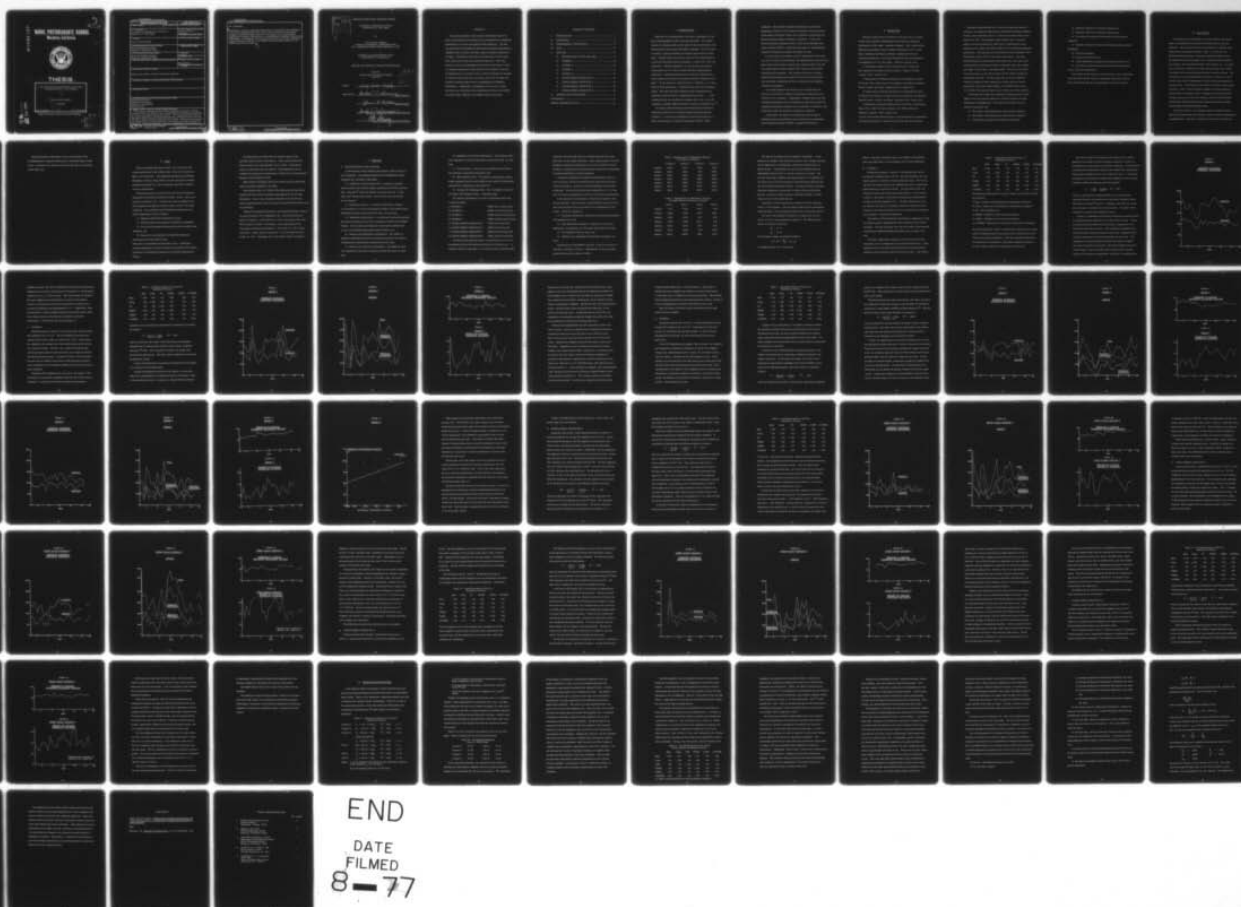AD-A041 167   NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF                    F/G 13/10
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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# Master's THESIS

AN ANALYSIS OF MAINTENANCE FACTORS
ON SELECTED U.S. NAVY SHIPS

by

Jerry Carson Grigsby

June 1977

Thesis Advisor:                    M. G. Sovereign

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maintenance varied as additional maintenance requirements were scheduled; 2) how the accomplishment of preventive versus corrective maintenance changed as funds for repair parts were increased; and 3) how the ships' employment schedules affected their accomplishment of shipboard maintenance. Additionally, an hypothesis test was used to show that there was a difference in the maintenance activity of the EMRM test group ships compared to the EMRM control group ships.

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An Analysis of Maintenance Factors
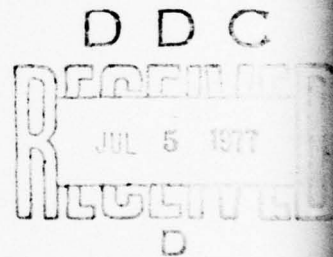on Selected U.S. Navy Ships

by

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Lieutenant Commander, United States Navy
B.S., Northeastern State College (Oklahoma), 1964

Submitted in partial fulfillment of the
requirements for the degree of

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# ABSTRACT

This study examined certain reported maintenance factors to better understand how they influence the accomplishment of shipboard maintenance in cruisers and guided missile destroyers. The data was generated by the Equipment Maintenance and Related Maintenance (EMRM) Project, Pacific, and other reports normally submitted by the ships. Though part of the data was broken down to work center level, this research did not go below the ship level. This study showed 1) how the accomplishment of preventive maintenance varied as additional maintenance requirements were scheduled; 2) how the accomplishment of preventive versus corrective maintenance changed as funds for repair parts were increased; and 3) how the ships' employment schedules affected their accomplishment of shipboard maintenance. Additionally, an hypothesis test was used to show that there was a difference in the maintenance activity of the EMRM test group ships compared to the EMRM control group ships.

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# I. INTRODUCTION

High level of accomplishment of preventive maintenance is one key to attaining higher levels of material readiness. New weapon systems are designed with specific goals for lower maintenance cost (both material and personnel) and higher reliability. For one reason or another, material readiness has usually come up short of these goals. Officials high up in the Navy structure have expressed their concern for improving material readiness. On March 18, 1975, the Honorable J. William Middendorf, II, then Secretary of the Navy, stated before the U.S. House of Representatives Appropriations Committee, "Achieving maximum force readiness within the manpower resources and budget constraints directed by Congress is our goal."[1] On the same day, Admiral James L. Holloway, U.S. Navy, Chief of Naval Operations, in testifying before the same committee, stated, "Our most important challenge is that of maximizing our readiness to meet the Navy's undiminished force levels. ... I am emphasizing that our attention and energies must be focused on the maximum readiness within the limits of resources available to us."[2]

The Chief of Naval Operations has indicated his priorities for achieving maximum force readiness through improved material readiness. A course was established for senior naval officers to better prepare them to control the maintenance efforts of their

commands. Major studies (Equipment Maintenance and Related
Maintenance Projects) of the Planned Maintenance System programs
in the Atlantic and Pacific Fleets were conducted to provide data for
decision making in ships' maintenance programs. In May 1976,
Naval Sea Systems Command issued a "Plan for the Extended Main-
tenance Analysis (EMA)", which dealt with plans for redesigning the
equipment maintenance programs throughout the Navy.

In recent years, the military services' budgets have been under
very close scrutiny by the Congress, the Administration, and the press.
Many critics of the military services have expressed their view that
less funds should be made available to the military while favoring
expanding social programs. The resultant pressures on funding,
coupled with escalating procurement cost and increased personnel
cost has further constrained the Navy's operational and equipment
maintenance programs.

It is readily apparent that the Navy must carefully plan and
execute its operations to achieve the maximum training which con-
tributes to force readiness. Additionally, problems associated with
equipment maintenance must be identified and understood so that the
equipment maintenance programs may be modified, if necessary, and
monitored to make the greatest contribution to readiness.

In this paper, the author will examine data with the goal of
identifying some of the problem areas and finding the relationships
between different factors involved in equipment maintenance.

## II. OBJECTIVES

Numerous studies have been made over the years to try to estab-

lish the most important relationships between inputs to equipment

maintenance and the output - material readiness. Four recent studies

addressed the problem of how to improve maintenance on U.S. Navy

ships, examining maintenance problems, management concerns

regarding maintenance, and factors affecting the level of maintenance

accomplishment on U.S. Navy ships. These four studies were:

(1) Production by Ship's Force During Overhaul, Report #82,

Navy Manpower and Material Analysis Center, Atlantic, Norfolk,

Virginia 23511, January 1973,

(2) Improvement of Planned Maintenance Accomplishment within

the Pacific Fleet, Report #138, Navy Manpower and Material Analysis

Center, Pacific, San Diego, California 92132, August 1974,

(3) Improvement of Planned Maintenance Accomplishment within

the Pacific Fleet (Phase II) Report #138A, Navy Manpower and Material

Analysis Center, Pacific, San Diego, California 92132, March 1975,

(4) Maintenance Personnel Effectiveness in the Navy, Professional

Paper #143, Center for Naval Analysis, 1401 Wilson Boulevard,

Arlington, Virginia 22209, January 1976.

The last of the studies listed was part of an ongoing study of maintenance

personnel effectiveness, conducted by the Center for Naval Analysis.

Because of continued high-level concern for improving material readiness, the Equipment Maintenance and Related Maintenance (EMRM) Projects were conducted in the U.S. Atlantic and Pacific Fleets during Fiscal Year 1976. The purpose of these projects was to study the impact of increased funding for repair parts on maintenance accomplishment and to collect data which could be used in improving shipboard maintenance. The projects ran from November 1975 to September 1976 and involved nearly 100 U.S. Navy ships in both fleets. The ships which participated in the projects were divided into a test group and a control group and represented surface combatants, fleet tugs, amphibious ships, aviation ships, and supply ships. The basis for inclusion in the test group or in the control group was the funding available for maintenance material. The test group ships were given additional funding for support of their maintenance activity while the control group ships were given normal funding. The EMRM Project in the U.S. Pacific Fleet was the major source of data used in this research.

In this paper these data were analyzed to determine which factors appear to have the greatest influence on material readiness through maintenance accomplishment. The major factors which were considered in this paper were

(1) The number of PM Maintenance Requirements scheduled,

(2) The number of PM Maintenance Requirements completed,

(3) Total Manhours utilized for equipment maintenance,

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(4)   Manhours utilized for Preventive Maintenance,

(5)   Manhours utilized for Corrective Maintenance,

(6)   Percentage of scheduled PM Maintenance Requirements completed,

(7)   Manhours utilized for PM per PM Maintenance Requirement Completion,

(8)   Personnel Manning,

(9)   Days spent In-port/At-sea,

(10)   Funds expended for equipment maintenance material, and

(11)   The ratio of manhours utilized for Preventive Maintenance versus Corrective Maintenance.

The purpose of this study was to help develop a better understanding of how these factors interact in equipment maintenance and how these interactions affect the accomplishment of this maintenance.

## III. PROCEDURE

It is difficult, if not impossible, to directly measure the impact
which accomplishment of preventive maintenance has on material
readiness.  This is largely because of the difficulty in finding a good
measurement of material readiness, itself.  For instance, the
Material Readiness Ratings, reported by many of the ships during
the EMRM Project did not appear to be a reflection of their mainten-
ance activity, their operating schedule, their funding, etc.  An indica-
tion of this lack of reflection was shown when the ships were ranked
according to their average reported Material Readiness Ratings.  The
averages for the reported maintenance factors (by ship) were scaled
to show their relative displacement from their mean (among ships of
the same type).  The ships were then ranked according to these scaled
averages.  Table 1 shows the ships' ranking by Material Readiness
Rating (MRR), the number of other rankings in which the ships hold
the same position as in the above ranking, and the average displace-
ment (absolute difference) between the maintenance factors rankings
and the Material Readiness Rating listing.

As shown in Table 1, the ranking by Material Readiness Rating
does not correspond with the rankings of ships according to maintenance
accomplishment.  Therefore, the Material Readiness Rating did not

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Table 1. Rankings of EMRM Ships

| Material Readiness Rating (MRR) (descending order) | Times Other Rank Same as MRR | Average Displacement from MRR |
|---|---|---|
| Cruiser B | 1 | 2.0 |
| Cruiser D | 0 | 4.6 |
| DDG H | 1 | 2.8 |
| DDG G | 0 | 2.4 |
| DDG F | 2 | 1.8 |
| DDG E | 0 | 3.4 |
| Cruiser C | 1 | 1.4 |
| Cruiser A | 0 | 5.2 |

appear to be a suitable measure of effectiveness for this study. Because the problems of devising a reliable measure of material readiness were the subjects of other studies, the assumption was made that accomplishment of preventive maintenance positively contributes to higher material readiness. It followed that preventive maintenance which was scheduled should have been completed and that the factors should be analyzed to find those which are statistically related to preventive maintenance accomplishment. Therefore, accomplishment of preventive maintenance was a general measure of effectiveness used in the analysis of the data.

In this study, most of the analysis was done using graphs depicting changes of the individual factors over time. In some cases, important

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conclusions can be drawn about how a factor acts over time. In most cases, the comparison of different factors at the same points in time was deemed to be more important. If there appeared to be close correlation between factors, regression analysis was used to check this relationship. At times, two factors may change very consistently relative to each other but may have a small coefficient of determination ($R^2$) due to difficulties in fitting the appropriate curve to the data. Therefore, graphical analysis was done first, then regression analysis was done, where it appeared to be appropriate, to check the strength of the relationships. Further, graphical analysis often shows trends or tendencies which are not apparent when only regression analysis is done.

Because of differences between ships and their employment during the period of time being studied, their data were analyzed individually. Generalizations and comparisons between ships were made where these appeared to be appropriate.

Many of the problems associated with equipment maintenance are time or situation dependent, making it difficult to draw generalities. When this appeared to be the case, the author presented the point without efforts at generalization. In analyzing the effects of the ship's operating schedule and changes in expenditures on the maintenance factors, consideration was given to the likelihood that the schedule and expenditure changes might cause anticipatory or lagged responses.

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Since the purpose of this paper is not to call attention to the accomplishments or apparent deficiencies of individual ships or their crews, no reference was made to the name of the ship in the analysis of that ship's data.

# IV. DATA

When one attempts this type of study, he is often faced with serious deficiencies in the available data, either in the amount of data or in its relevance. The Equipment Maintenance and Related Maintenance Project, along with the records and reports normally available from major U.S. Navy commands, provided a wealth of current, relevant data.

The principal source of data for this study was the Equipment Maintenance and Related Maintenance Project, Pacific, which commenced in November 1975. This data was used as supplied by the Navy Manpower and Material Analysis Center, Pacific, San Diego, California. Data available from the Equipment Maintenance and Related Maintenance Project included:

(1) Manhours utilized for maintenance activity,

(2) PM Maintenance Requirements scheduled and completed,

(3) Corrective Maintenance-Maintenance Actions scheduled and completed, and

(4) Reasons for noncompletion of scheduled maintenance requirements and maintenance action.

These data were tabulated and reported by week. Additionally, monetary expenditures by ship by month were available from reports generated by the Equipment Maintenance and Related Maintenance Project.

Personnel data were taken from the summary pages of the individual ship's NavPers 1080 reports. These reports showed the ship's manning level, approximately once a month. Unfortunately, turnover of personnel was not reflected. Ship employment was as scheduled according to the Commander-in-Chief Pacific Fleet Quarterly Schedule (CinCPacFltNote C3120).

Ship's Material Readiness Rating were taken from the operational reports normally submitted by the ships.

Approximately fifty U.S. Pacific Fleet ships provided data which included both work center information and aggregated (for the ship) information. Since it was considered infeasible to use all the data, only the aggregated data from the cruisers and guided missile destroyers were analyzed.

Though the Equipment Maintenance and Related Maintenance Project ran from November 1975 to September 1976, only the data from the period, November 3, 1975 until May 16, 1976, were used in this study. When reference is made, in this paper, to the study period or the test period, the period of November 3, 1975 to May 16, 1976 is being referred to. Week 1 ended on November 9, 1975 and Week 28 ended on May 16, 1976. (Christmas 1975, was between Week 7 and Week 8.)

# V. ANALYSIS

## A. INTRODUCTION TO THE ANALYSIS

In the discussion of the analysis which follows certain terms are used repeatedly. The following definitions and amplifications apply throughout the remainder of this paper:

(1) Coefficient of Determination ($R^2$) - A measure commonly used to describe how well the sample regression line fits the observed data. Note that $R^2$ cannot be negative or greater than one. A zero value of $R^2$ indicates the poorest, and a unit value the best fit that can be attained.[3]

(2) Maintenance Action - A corrective maintenance response to a discrepancy on an item of equipment included in the EMRM Project. Maintenance Actions were tabulated by week, for each ship.

(3) Maintenance Requirement - A requirement to perform specified preventive maintenance on an item of equipment included in the EMRM Project. This includes all maintenance requirements whether they are part of the Planned Maintenance System (PMS) or not.

(4) Manhours per Maintenance Requirement - The number of manhours expended on preventive maintenance divided by the number of maintenance requirements completed during that week.

(5) Manhours for Preventive Maintenance - All manhours which were expended on preventive maintenance during that week, for each ship.

(6) Manhours for Corrective Maintenance - All manhours which were expended on corrective maintenance during that week, for each ship.

(7) Total Manhours - The sum of the manhours for preventive and corrective maintenance during that week.

(8) PM Completion Rate - The number of maintenance requirements completed during a week divided by the number of maintenance requirements scheduled that week times 100.

(9) Average PM Completion Rate - The (unweighted) average of the weekly PM Completion Rates. (Individual ships)

The following designations are used for identifying which ship is being discussed:

| | |
|---|---|
| (1) CRUISER A | EMRM Test Group Cruiser |
| (2) CRUISER B | EMRM Test Group Cruiser |
| (3) CRUISER C | EMRM Control Group Cruiser |
| (4) CRUISER D | EMRM Control Group Cruiser |
| (5) GUIDED MISSILE DESTROYER E | EMRM Test Group DDG |
| (6) GUIDED MISSILE DESTROYER F | EMRM Test Group DDG |
| (7) GUIDED MISSILE DESTROYER G | EMRM Control Group DDG |
| (8) GUIDED MISSILE DESTROYER H | EMRM Control Group DDG |

One of the most important factors in determining the success of an analytical study is the selection of measures of effectiveness. As alluded to earlier in this paper, an accurate material readiness index

would have been the ideal measure of effectiveness for this study. Since this was not readily attainable, certain measurements of accomplishment of preventive maintenance were used as measures of performance, assuming that better performance of preventive maintenance contributes positively to material readiness.

Corrective maintenance is tentatively established by CNO at a ratio of one hour corrective maintenance for each two hours of preventive maintenance, except corrective maintenance for electronic equipments. The ratio for the electronic equipments is 1:1, or one hour of corrective maintenance to one hour of preventive maintenance.

In the discussion of the analysis, at least four graphs for each ship are included. Not all of these are specifically referenced in the text of the discussion but are included for the enlightenment of the reader. These four graphs are

(1) Preventive Maintenance-Maintenance Requirements Scheduled and Completed per Week,

(2) Total Maintenance Manhours, Manhours for Corrective Maintenance, and Manhours for Preventive Maintenance per Week,

(3) PM Completion Rate per Week, and

(4) 'Manhours per Maintenance Requirement Completion' per Week.

Expenditures for maintenance material, by the four cruisers in this study, are shown in Table 2. Expenditures by the four guided missile destroyers are shown in Table 3.

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## Table 2: Expenditures for Maintenance Material
by Cruisers (In dollars)

|         | Cruiser A | Cruiser B | Cruiser C | Cruiser D |
|---------|-----------|-----------|-----------|-----------|
| Month 1 | 16630     | 10271     | 9248      | 14777     |
| Month 2 | 43242     | 30581     | 7457      | 28772     |
| Month 3 | 46801     | 32620     | 8920      | 20851     |
| Month 4 | 33461     | 45762     | 15853     | 15844     |
| Month 5 | 24057     | 33949     | 22757     | 14363     |
| Month 6 | 48143     | 38691     | 19134     | 38717     |
| Month 7 | 42614     | 50746     | 18961     | 16410     |

## Table 3: Expenditures for Maintenance Material
by Guided Missile Destroyers (In dollars)

|         | DDG E  | DDG F  | DDG G | DDG H |
|---------|--------|--------|-------|-------|
| Month 1 | 9111   | 27060  | 16350 | 7649  |
| Month 2 | 18888  | 13890  | 11487 | 10553 |
| Month 3 | 14083  | 41196  | 9747  | 6685  |
| Month 4 | 13220  | 43448  | 10763 | 5738  |
| Month 5 | 29952  | 41912  | 8977  | 8342  |
| Month 6 | 36195  | 49284  | 5739  | 10740 |
| Month 7 | 103152 | 105905 | 8827  | 15187 |

The data for the ships was first analyzed, individually. In this analyses, the graphs of the maintenance factors were visually examined for the appearance of relationships, between the different pairs of plotted factors. Consideration was given to the possibility that the relationship could be direct or inverse; concurrent or lagged. The records of the ships' manning, operating schedules, and expenditures for repair parts were then examined to determine what influences they had on the plotted maintenance factors. Regression analysis was done when there appeared to be possible correlation between the plotted factors, or between a ship's manning, operating schedule, or expenditures and any of the plotted factors.

Discussions of these analyses are included in Section B through Section I of this chapter. The last chapter deals with the commonality, among all ships, of the relationships between the maintenance factors.

For each of the regression equations, the slope value (B) was tested, to see if it was statistically significant. The following hypothesis was used for these tests:

$$H_o \;:\; B = 0$$

$$H_1 \;:\; B \neq 0$$

The acceptance region was defined as follows:

$$-t_{n-2, a/2} \; / \; \frac{B}{s_B} \quad t_{n-2, \, a/2}$$

A confidence level (a) of .01 was used.

Where a regression equation is given, the numbers in parenthesis, below the coefficients, are the standard errors of the coefficients.

B. CRUISER A

During the test period, Cruiser A, a test group ship, had an average PM completion rate of 59.7%. The PM completion rate was fairly constant, in the fifty to seventy percentile range. There were only three occasions when the rate changed more than ten percentage points between two consecutive weeks. (In one of these cases, the change was greater than twenty percentage points.) As can be seen in Table 4, the number of maintenance requirements scheduled had no effect on the PM completion rate. The PM completion rate was not related to the number of manhours utilized for preventive maintenance or corrective maintenance nor was it related to the manhours per maintenance requirement completion.

The number of PM maintenance requirements completed per week was almost constant (approximately 1000) regardless of the number scheduled. The only exceptions were when the number of maintenance requirements scheduled dropped drastically from one week to the next.

The ship's employment schedule (at-sea versus in-port) had little effect on its accomplishment of preventive maintenance. There appeared to be a very weak relationship between total maintenance manhours and the number of days the ship was in-port. Also toward

### Table 4. Correlation Matrix of Cruiser A's Maintenance Factors

|        | Sked  | Comp   | CR     | PMMH  | CMMH   | AvPMMH |
|--------|-------|--------|--------|-------|--------|--------|
| Sked   | 1.000 | .672   | -.592  | .132  | .024   | -.118  |
| Comp   | .672  | 1.000  | .185   | .372  | -.207  | .002   |
| CR     | -.592 | .185   | 1.000  | .221  | -.226  | .152   |
| PMMH   | .132  | .372   | .221   | 1.000 | .402   | .923   |
| CMMH   | .024  | -.207  | -.226  | .402  | 1.000  | .529   |
| AVPMMH | -.118 | .002   | .152   | .923  | .529   | 1.000  |

The following abbreviations are used in Table 4 and the other Correlation Matrices:

(1) Sked - Number of PM maintenance requirements scheduled

(2) Comp - Number of PM maintenance requirements completed

(3) CR - PM completion rate

(4) PMMH - Manhours for preventive maintenance

(5) CMMH - Manhours for corrective maintenance

(6) AVPMMH - Manhours per maintenance requirement completion.

the end of the period, Cruiser A commenced an extended stay in-port which corresponded with an increasing trend in manhours per maintenance requirement completion. Both total maintenance manhours and manhours per maintenance requirement completion seemed to be more closely related to the manning level of the ship.

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The effect of under/over manning of the ship's crew is readily apparent in the number of total maintenance manhours as well as in the manhours per maintenance requirement completion. Trends toward increasing total maintenance manhours and manhours per maintenance requirement completion can be seen in Figures 2 and 3. A regression of manhours per maintenance requirement completion versus manning surpluses yielded the following regression equation

$$Y_i = 1.415 - 0.013M_i, \quad R^2 = .8235$$
$$\quad\quad (.05) \quad\; (.005)$$

where $M_i$ represents the manning deficit and $Y_i$ represents the estimated manhours per maintenance requirement completion which will result in that (the $i^{th}$) month. It should be noted that this regression was done on a sample with six observations. The slope value's significance was proven by hypothesis testing.

Cruiser A's expenditure of funds for maintenance material started at approximately the same level as the other three cruisers. During the second and third months of the test period, expenditures were about three times the start level. The expenditures dropped during the fourth month to about two times the start level, dropping further, during the fifth month to one and a half times the start level. The expenditures increased sharply during the sixth month to slightly more than for months two and three, then fell off slightly during the seventh month. None of the other factors demonstrated changes similar to the changes in expenditures, except that, as expenditures

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FIGURE 1

CRUISER A
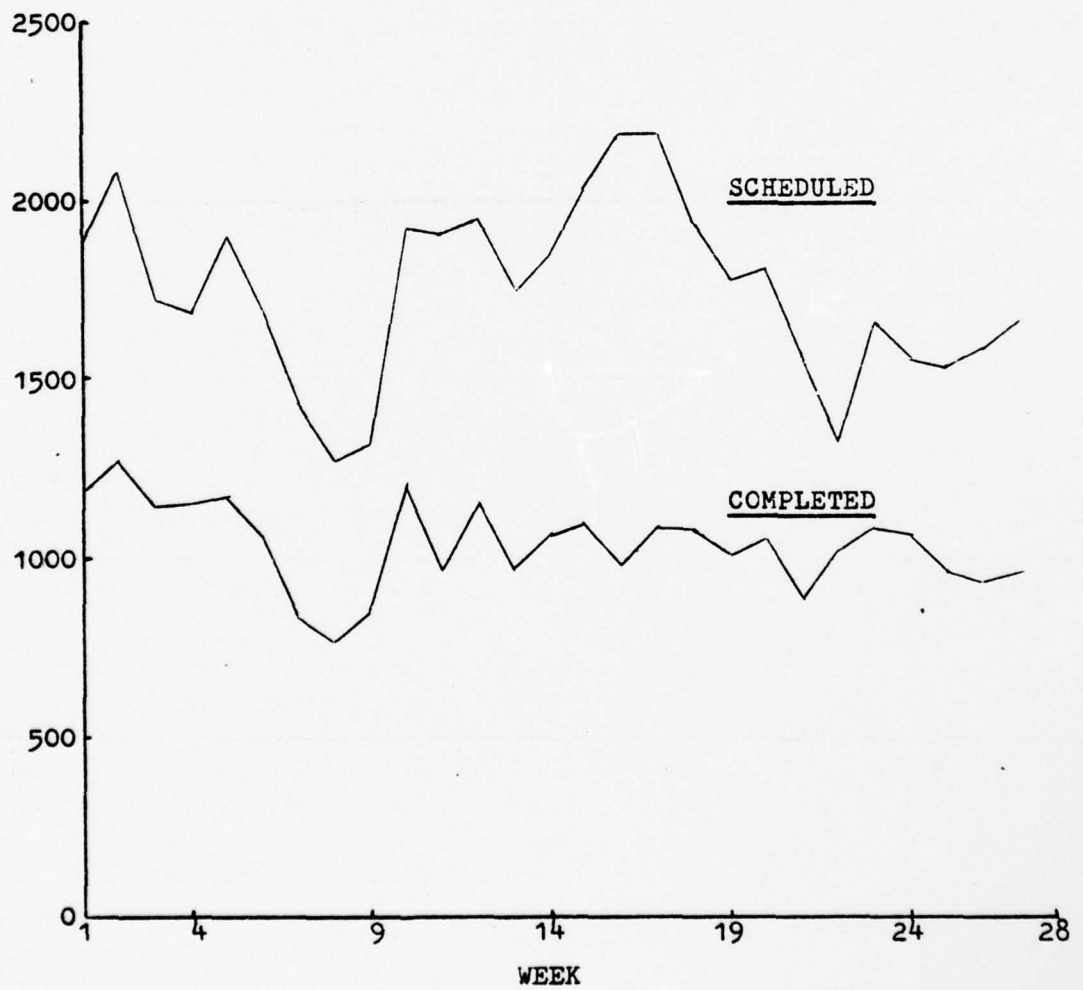
PREVENTIVE MAINTENANCE
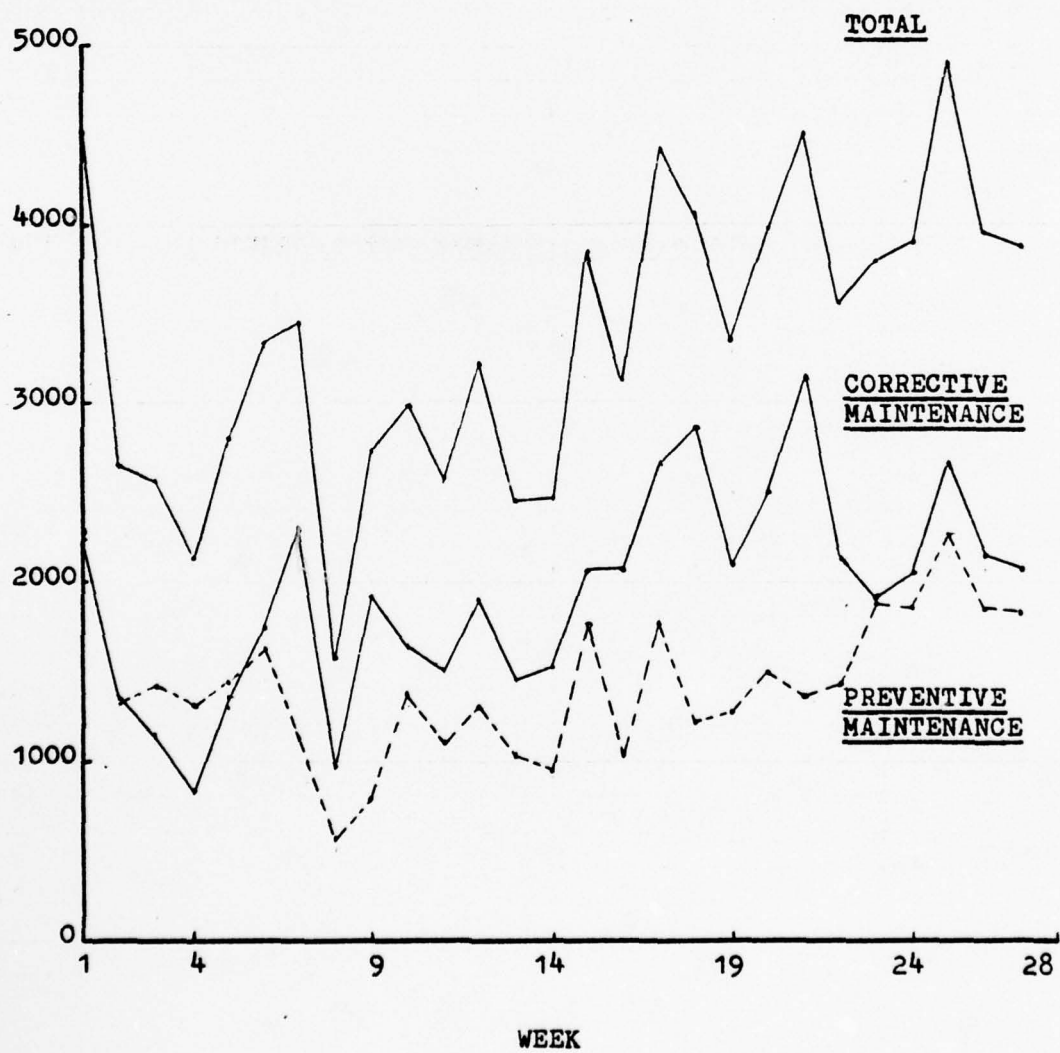MAINTENANCE REQUIREMENTS

FIGURE 2

CRUISER A

MANHOURS

## FIGURE 3

## CRUISER A
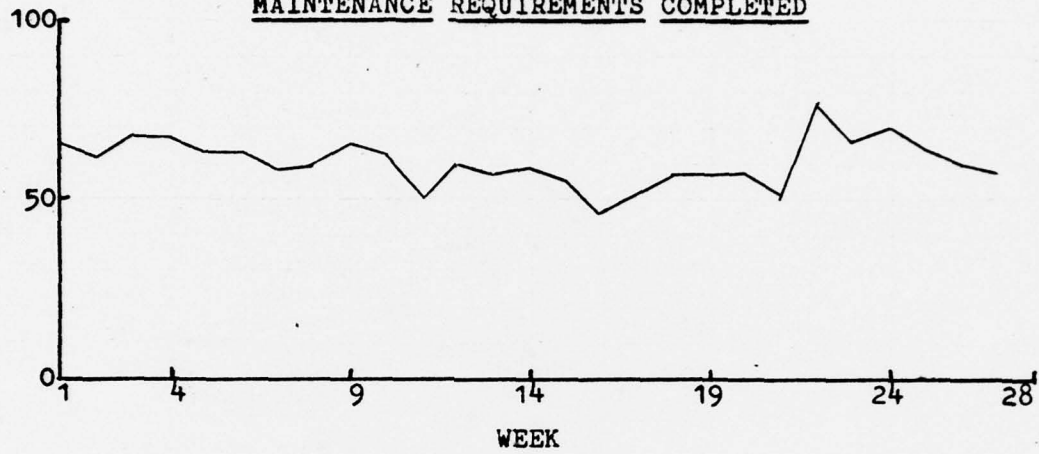
### PERCENTAGE OF SCHEDULED
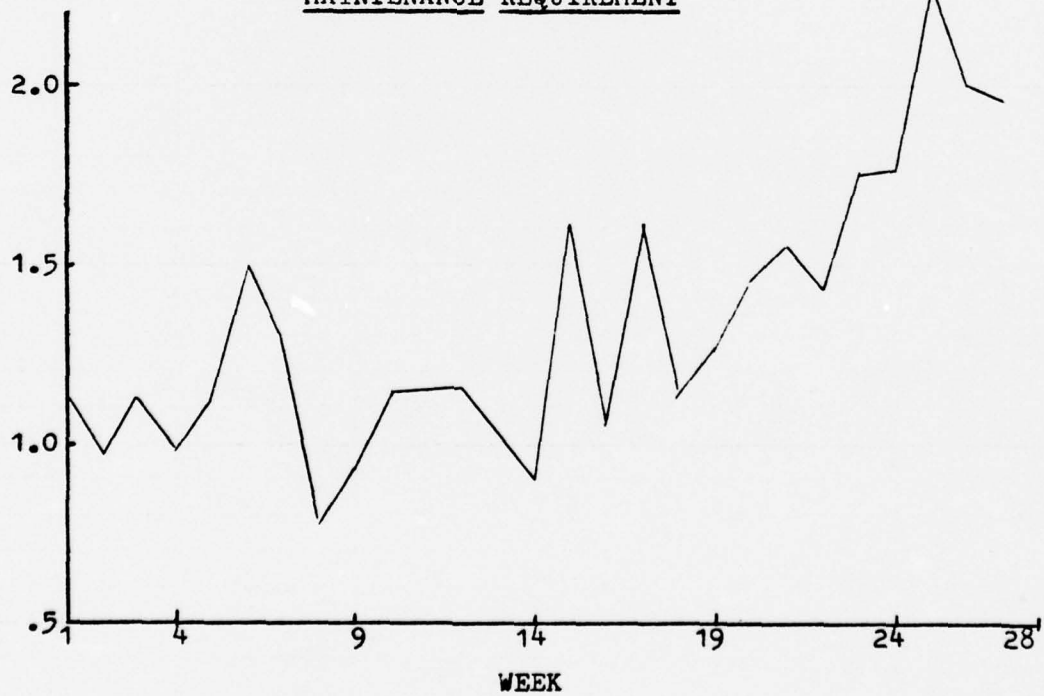### MAINTENANCE REQUIREMENTS COMPLETED



WEEK

## FIGURE 4

## CRUISER A

### MANHOURS PER COMPLETED
### MAINTENANCE REQUIREMENT



WEEK

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initially increased, the ratio of manhours for preventive maintenance to manhours for corrective maintenance decreased past 1:1 and remained outside the 2:1 to 1:1, PM:CM range. This was probably an indication that more emphasis was being placed on corrective maintenance. Cruiser A's manhours for preventive maintenance to manhours for corrective maintenance was approximately 1:1.5. Additionally, when the expenditure of funds dropped sharply during the fifth month, there was a slight decrease in the manhours utilized for preventive maintenance. (The PM:CM ratio went to almost 2:1.)

C.   CRUISER B

During this period, Cruiser B, a test group ship, had an average PM completion rate of 61.6%. The PM completion rate fluctuated radically from week to week in a range of 46% - 83%. Twelve times the completion rate changed more than ten percentage points between two consecutive weeks. Of these, two changes were greater than twenty percentage points but less than thirty; one change was greater than thirty percentage points. As shown in Table 5, the PM completion rate was not related to the number of PM maintenance requirements scheduled or to the manhours utilized per maintenance requirement completion.

Though the PM completion rate was erratic, the number of PM maintenance requirements completed varied directly with the number scheduled. A regression of the PM maintenance requirements

Table 5.  Correlation Matrix of Cruiser B's
Maintenance Factors

|        | Sked   | Comp   | CR     | PMMH   | CMMH   | AvPMMH |
|--------|--------|--------|--------|--------|--------|--------|
| Sked   | 1.000  | .864   | .135   | .405   | .295   | -.291  |
| Comp   | .864   | 1.000  | .608   | .547   | .393   | -.224  |
| CR     | .135   | .608   | 1.000  | .498   | .343   | .081   |
| PMMH   | .405   | .547   | .498   | 1.000  | .566   | .669   |
| CMMH   | .295   | .393   | .343   | .566   | 1.000  | .317   |
| AvPMMH | -.291  | -.224  | .081   | .669   | .317   | 1.000  |

completed versus maintenance requirements scheduled gave the following equation:

$$C_i = -163.56 + .733S_i, \qquad R^2 = .7479$$
$$(130.7) \ (.089)$$

where $S_i$ represents the number of PM maintenance requirements scheduled and $C_i$ represents the estimate of the number completed during the $i^{th}$ week. This regression was done on a sample with twenty-seven observations. The slope value's significance was proved by hypothesis testing.

Cruiser B's performance of preventive maintenance did not appear to be related to her manning levels.

Though the employment schedule did not appear to consistently affect the accomplishment of scheduled preventive maintenance, some of the maintenance factors, on occasions, changed with the schedule.

# FIGURE 5

## CRUISER B

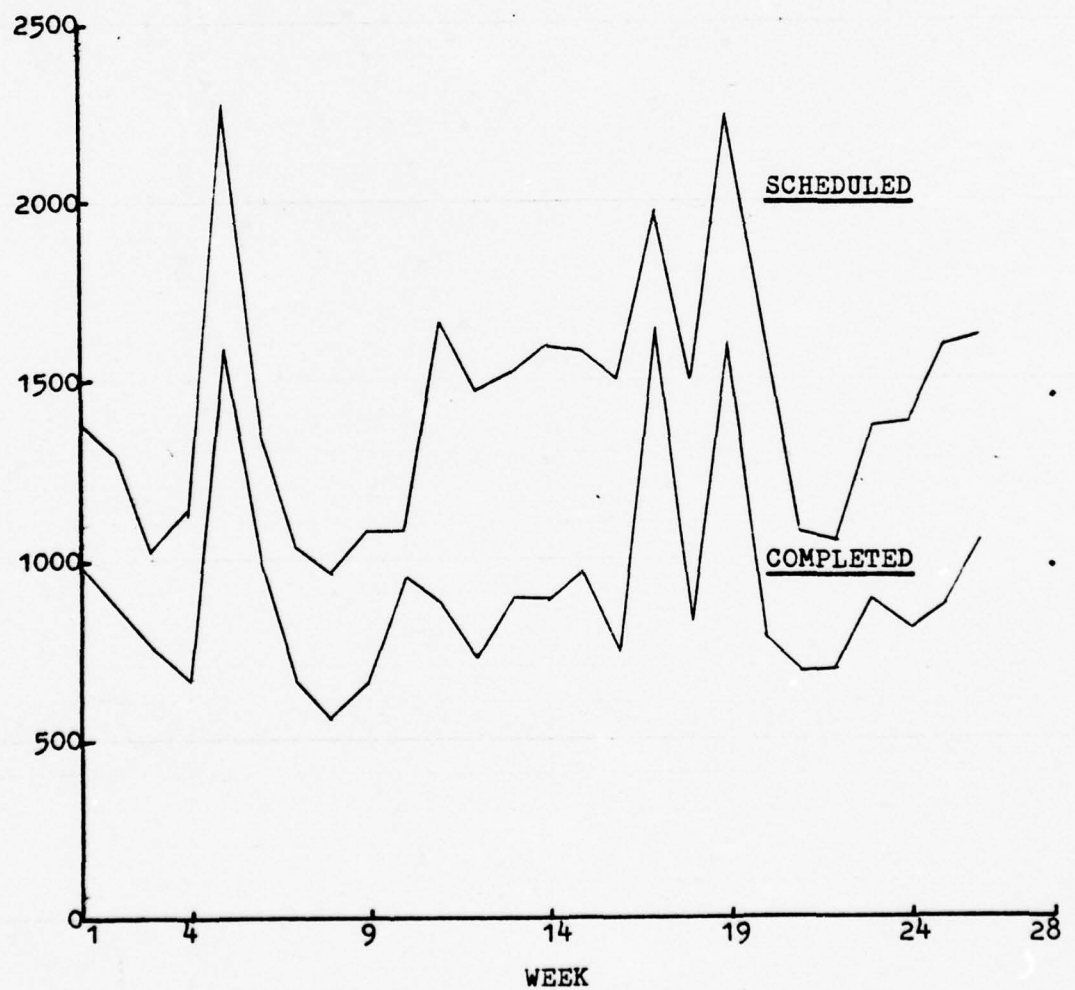### PREVENTIVE MAINTENANCE
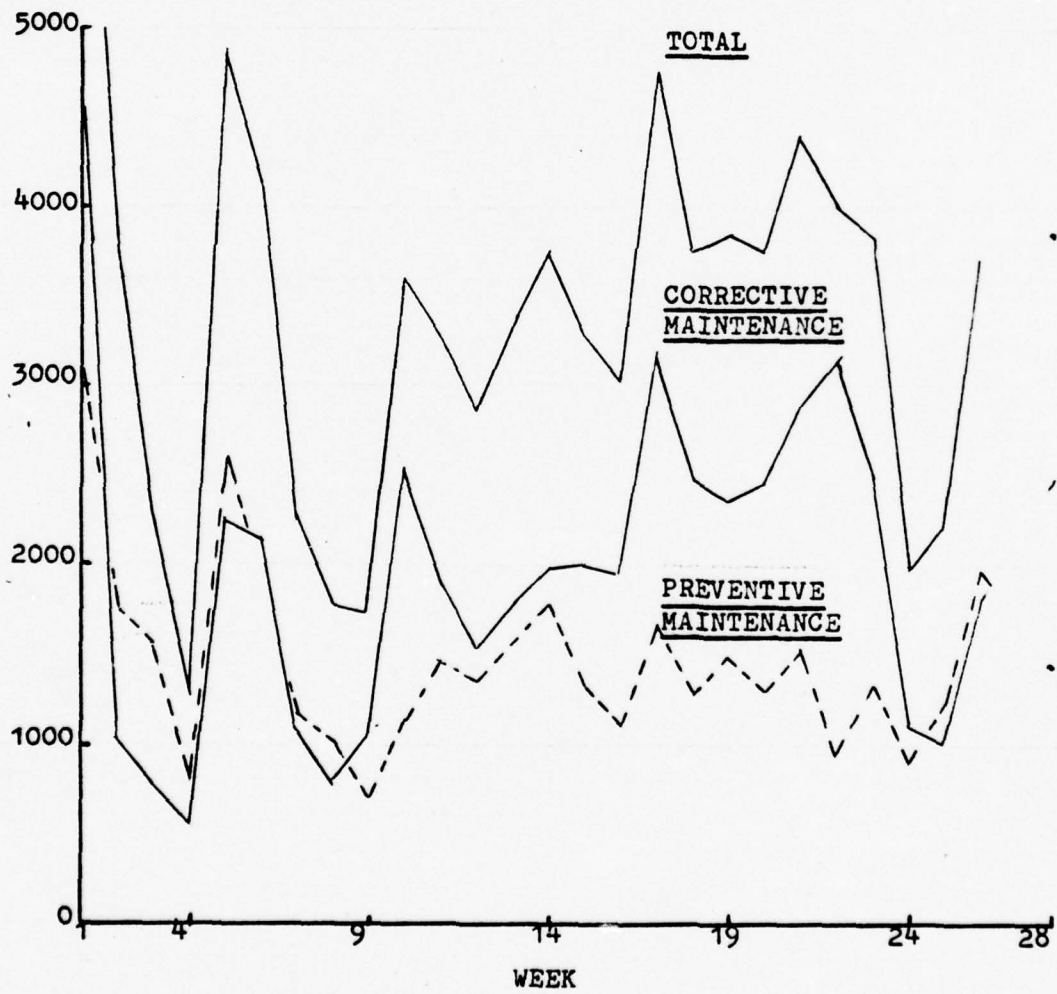### MAINTENANCE REQUIREMENTS



30

FIGURE 6

CRUISER B

MANHOURS

FIGURE 7

CRUISER B

PERCENTAGE OF SCHEDULED
MAINTENANCE REQUIREMENTS COMPLETED



WEEK

FIGURE 8

CRUISER B

MANHOURS PER COMPLETED
MAINTENANCE REQUIREMENT



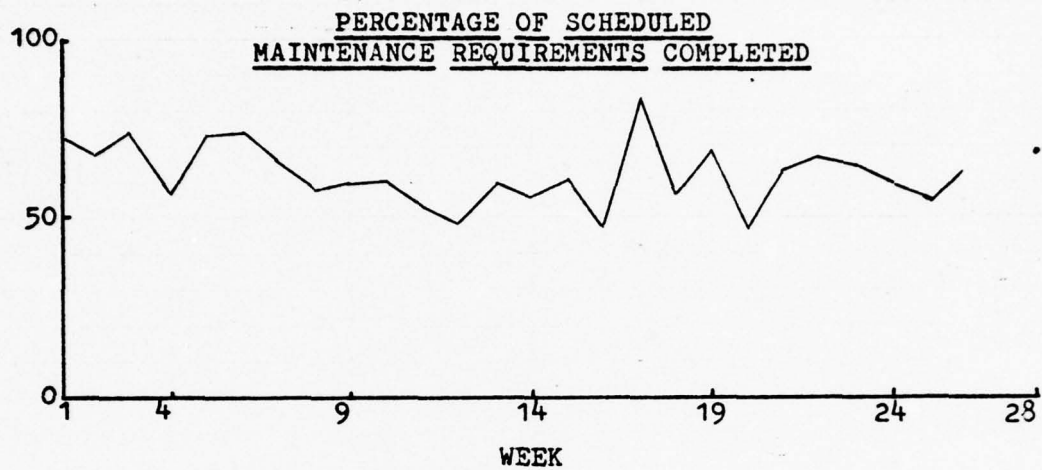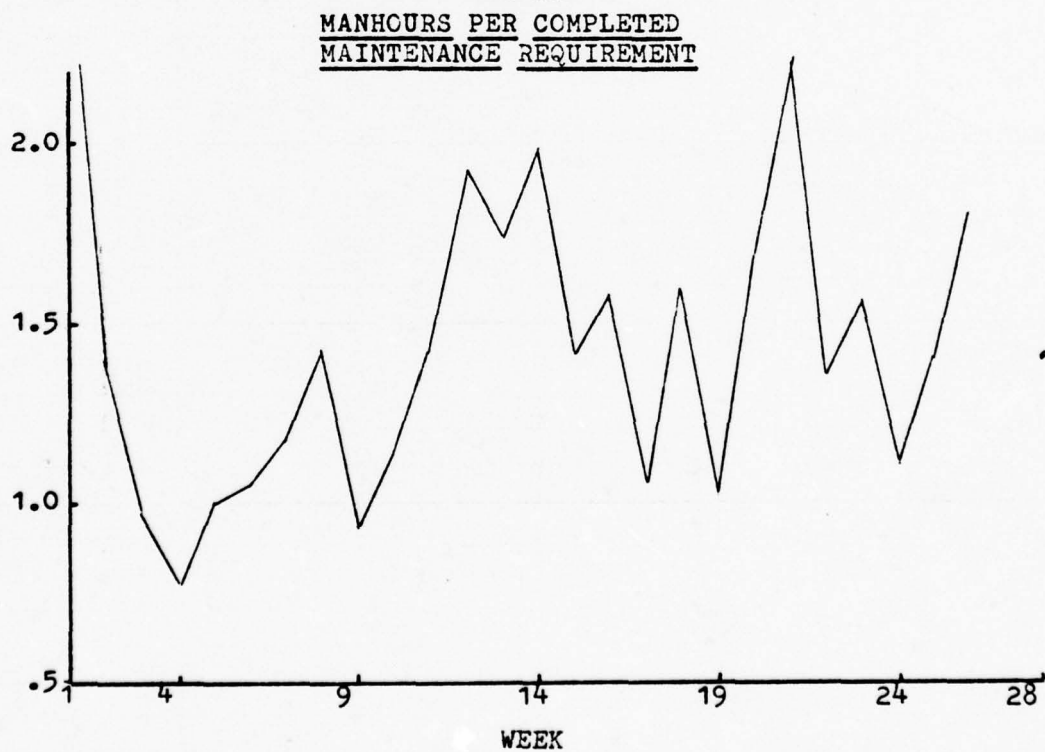WEEK

32

During the six week period, starting with the fourteenth week, there appears to be some relationship between the operational schedule and PM completion rate, manhours per maintenance requirement completion, manhours for preventive maintenance, and the number of maintenance requirements completed. During this time, the ship alternated, weekly, between being in-port continuously and operating, at sea, three to five days per week. At approximately the same time, the expenditures for maintenance material dropped from about five times the starting level to three and a half times that level.

Starting from approximately the same expenditure level as the other cruisers, Cruiser B's expenditures for maintenance material increased to about three times the start level in months two and three, then up to four and a half times the start level in the fourth month. Expenditures dropped during the fifth month to three and a half times. Expenditures were increased in the sixth and seventh months to four times and five times, respectively, the starting level. During the first nine weeks, the ratio of manhours expended for preventive maintenance to manhours for corrective maintenance was close to or within the 1:1 to 2:1 (PM:CM) range, after which the ratio decreased below 1:1. As the expenditures dropped, after the fourteenth week, manhours for preventive maintenance dropped slightly and the ratio decreased to almost 1:2. This condition continued until about the twenty-fourth week. (By which time expenditures had increased

to their previous high level.) As with Cruiser A, this seems to
indicate that more emphasis was shifted to corrective maintenance
as more funds were available for maintenance material. When expend-
itures dropped and operations disturbed maintenance efforts, decreases
in the accomplishment of preventive maintenance were noted.

Data for Cruiser B from the twenty-seventh week of the study
period were not available.

D.   CRUISER C

During the study period, Cruiser C, a control group ship, had an
average PM completion rate of 74.9%. During the first half of the
period, the completion rate declined steadily, but then increased
throughout the second half, not quite recovering to the previous
high levels.

As the PM completion rate dropped, then increased, the manhours
per maintenance requirement completion increased, then dropped.
Though some relationship may have existed, the correlation matrix,
shown in Table 6, revealed that the relationship was weak. These
changes may have been due to the ship being in-port continuously from
the sixth week of the study period until the twenty-first week, which
included most of the changes in PM completion rate and manhours per
maintenance requirement completion noted above. During the in-port
period, the manhours for preventive maintenance remained in a range
of 1000 - 1300 manhours per week.

### Table 6. Correlation Matrix of Cruiser C's Maintenance Factors

|        | Sked   | Comp   | CR     | PMMH   | CMMH   | AvPMMH |
|--------|--------|--------|--------|--------|--------|--------|
| Sked   | 1.000  | .674   | -.353  | .110   | -.022  | -.077  |
| Comp   | .674   | 1.000  | .450   | .090   | .017   | -.180  |
| CR     | -.353  | .450   | 1.000  | -.033  | .028   | -.149  |
| PMMH   | .110   | .090   | -.033  | 1.000  | .948   | .961   |
| CMMH   | -.022  | .017   | .028   | .948   | 1.000  | .937   |
| AvPMMH | -.077  | -.180  | -.149  | .961   | .937   | 1.000  |

Another source of disturbance to the ship's maintenance efforts was changes in manning which occurred during this in-port period. During the third month, the ship's manning dropped from nineteen below authorized manning to approximately twenty-eight below. The ship's manning was then increased back to nineteen below its authorized level and later to ten below.

A measure of the combined effects of these disturbances is the number of PM maintenance requirement completed compared to the number scheduled. For the whole test period, the number of PM maintenance requirements completed versus those scheduled can be shown by the following equation, which was derived by regression analysis:

$$C_i = 249.039 + 0.556S_i, \quad R^2 = .4542 ,$$
$$\quad (159.2) \quad (.12)$$

where $S_i$ represents the number of maintenance requirement scheduled

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and $C_i$ is an estimate of the number which would be completed during the $i^{th}$ week. This regression was done using all twenty-eight observations in the sample.

When the data from the twelve week period, when there was excessive instability in personnel manning, were excluded, the regression equation has a much higher coefficient of determination ($R^2$). With the data from those twelve weeks excluded, the equation is

$$C_i = 46.098 + .769S_i, \quad R^2 = .8299.$$
$$\phantom{C_i =} (13.46) \ (.01)$$

It was not possible to directly examine the effects of these changes in manning level, since there were too few observations in the sample. The slope value was proven to be significant in both of the above equations by the hypothesis test previously described.

Cruiser C's expenditures for maintenance material was at about the same level as those of the other cruisers at the start of the period. During the second and third months, expenditures dropped below that level, but increased during the fourth and fifth months so that during the fifth month, they were about two times the start level. During the sixth and seventh months, expenditures dropped off slightly from the level of the fifth month. The high level of expenditures in the fifth month was just before the ship got underway after fifteen weeks in-port. Maintenance manhours increased slightly during the third, fourth, and fifth months, but did not increase by the magnitude which

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# FIGURE 9

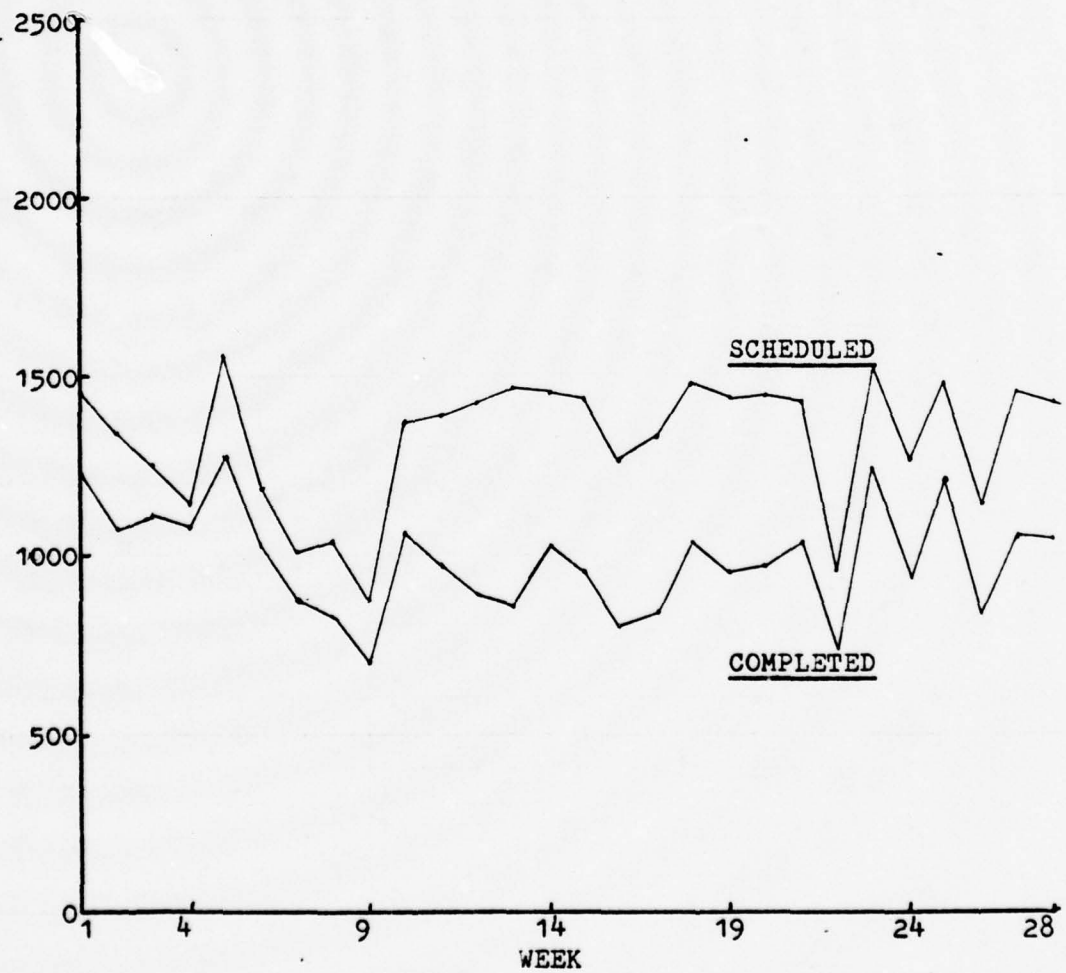## CRUISER C

### PREVENTIVE MAINTENANCE
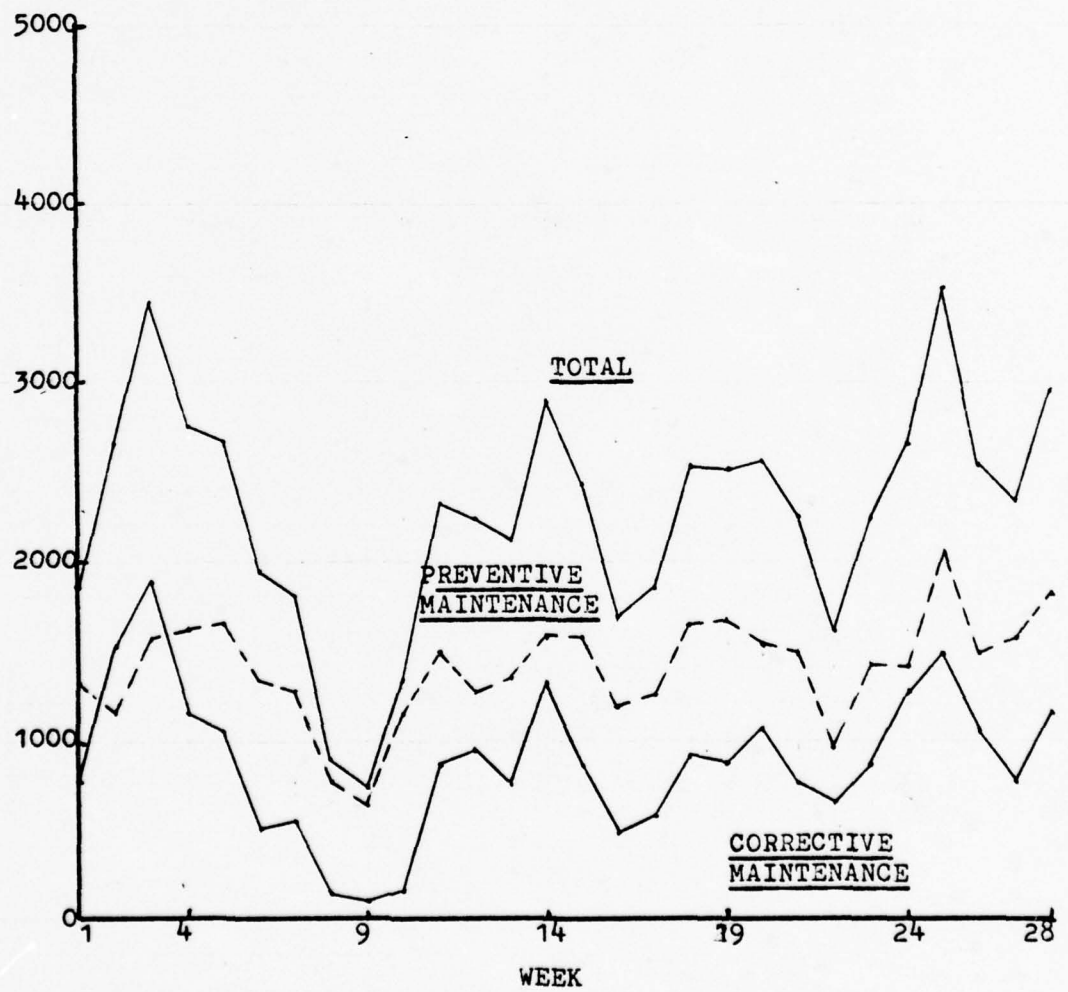### MAINTENANCE REQUIREMENTS

FIGURE 10

CRUISER C

MANHOURS

FIGURE 11

CRUISER C

PERCENTAGE OF SCHEDULED
MAINTENANCE REQUIREMENTS COMPLETED



FIGURE 12

CRUISER C

MANHOURS PER COMPLETED
MAINTENANCE REQUIREMENT
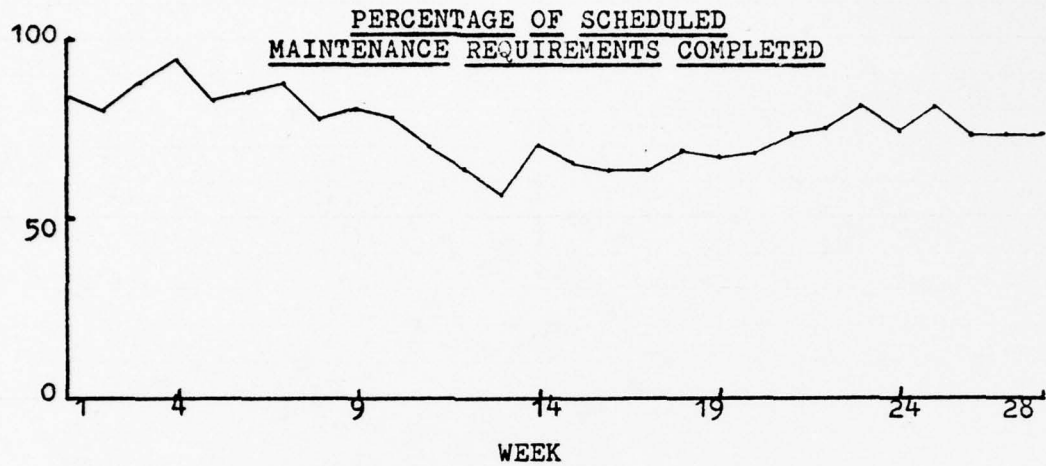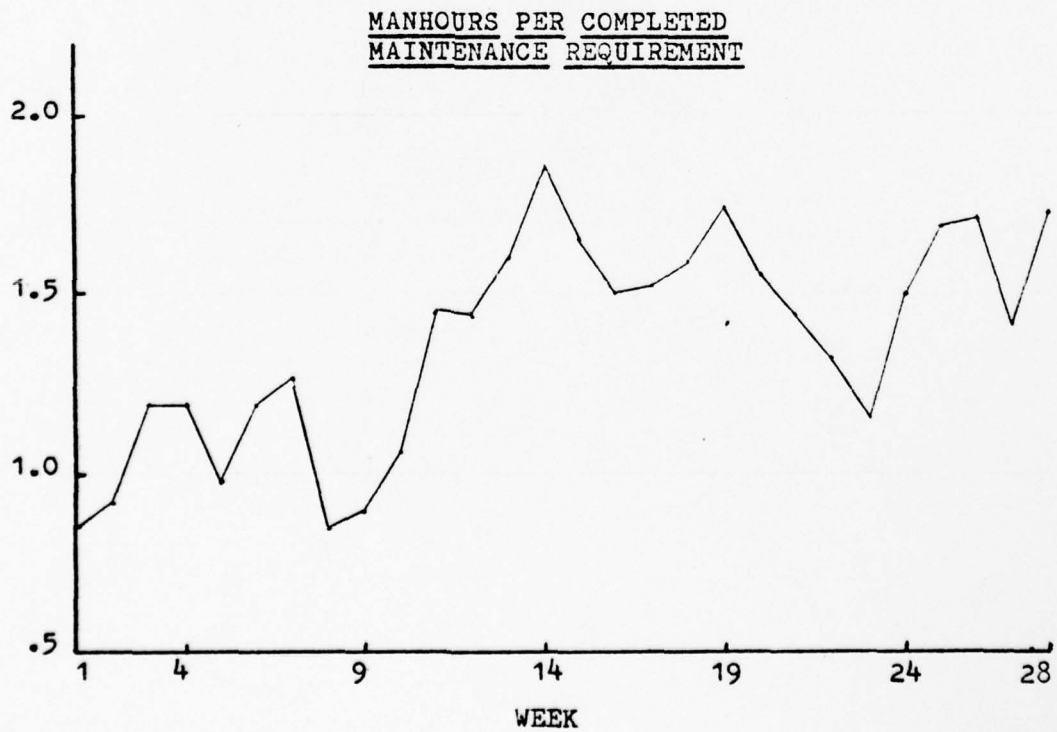


39

expenditures increased during the fifth month. The ratio of manhours for preventive maintenance to manhours for corrective maintenance was relatively constant throughout the period and was consistently between 2:1 and 1:1 (PM:CM).

E. CRUISER D

During the period of this study, Cruiser D, a control group ship, had an average PM completion rate of 70.6%. The PM completion rate was very stable from week to week but showed a steady, increasing trend. At the start of the period, the completion rate was approximately 60%; at the end, it had increased to over 80%.

As shown in the correlation matrix, Table 7, none of the relationships between the maintenance factors which were being investigated in this study, seemed to hold for Cruiser D. The graphs of PM maintenance requirements scheduled and completed appeared to indicate some relationship, but the regression of these two factors yielded a regression equation with a coefficient of determination ($R^2$) of only .4224. Since there appeared to be more correlation between these factors than was indicated by the $R^2$ of .4224, a plot, shown in Figure 17 was made. From this perspective, it is more apparent that the relationship was not as strong as was previously thought.

At the start of the period, Cruiser D was manned to approximately eighty below her authorized manning level. This was improved so

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### Table 7. Correlation Matrix of Cruiser D's Maintenance Factors

|        | Sked   | Comp   | CR     | PMMH   | CMMH   | AvPMMH |
|--------|--------|--------|--------|--------|--------|--------|
| Sked   | 1.000  | .649   | -.524  | .278   | .173   | -.085  |
| Comp   | .649   | 1.000  | .300   | .297   | .273   | -.294  |
| CR     | -.524  | .300   | 1.000  | -.006  | .094   | -.210  |
| PMMH   | .278   | .297   | -.006  | 1.000  | .399   | .820   |
| CMMH   | .173   | .273   | .094   | .399   | 1.000  | .237   |
| AvPMMH | -.085  | -.294  | -.210  | .820   | .237   | 1.000  |

that in the third month her manning was increased to approximately twenty-five below authorized manning. This manning level held until the end of the period. This increase in manning was not apparent in any of the other maintenance factors except, an increase in the PM completion rate, which occurred just prior to the manning increase, was sustained.

There was evidence of changes associated with the ship's employment schedule in the manhours per PM maintenance requirement completion and in manhours for corrective maintenance. Manhours per maintenance requirement completion were not constant but fluctuated from week to week, giving seven peaks of more than 1.3 manhours per completion. (Cruiser D's average manhours per completion was 1.22 manhours per completion, compared to the average of 1.366 for all four cruisers.) Of these, six were while the ship was at-sea.

41

# FIGURE 13

## CRUISER D
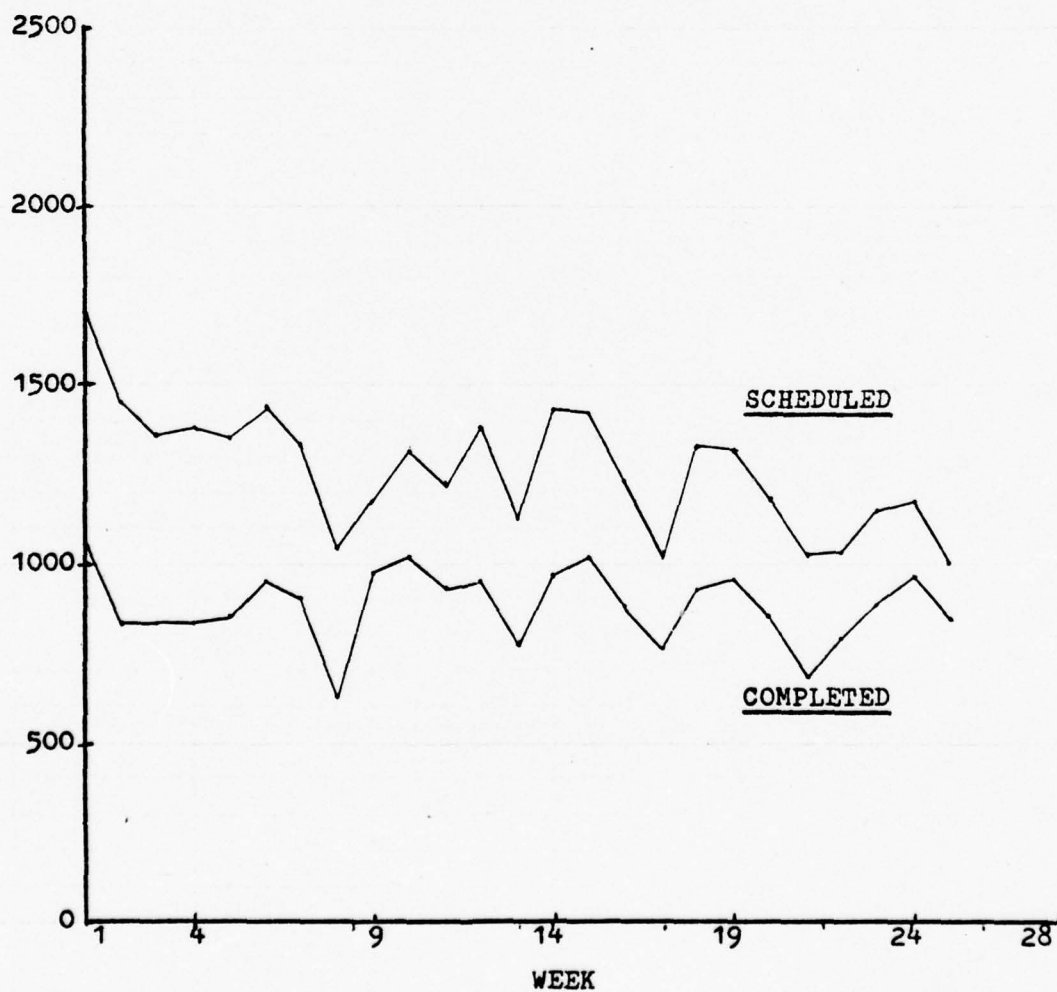
### PREVENTIVE MAINTENANCE
### MAINTENANCE REQUIREMENTS
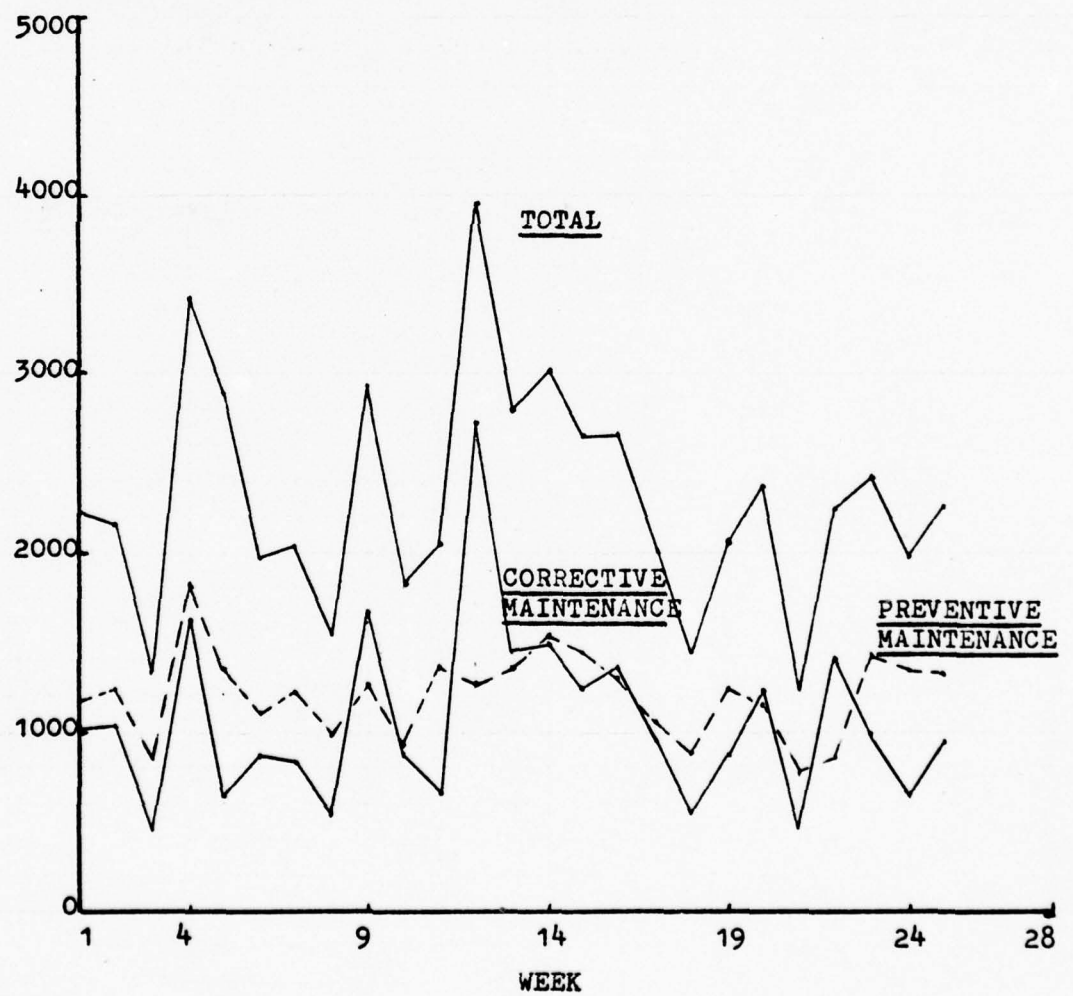


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FIGURE 14
CRUISER D

MANHOURS

## FIGURE 15

## CRUISER D

### PERCENTAGE OF SCHEDULED
### MAINTENANCE REQUIREMENTS COMPLETED



WEEK

## FIGURE 16

## CRUISER D

### MANHOURS PER COMPLETED
### MAINTENANCE REQUIREMENT



WEEK

44

# FIGURE 17

## CRUISER D



Scatter plot titled "MAINTENANCE REQUIREMENTS COMPLETED" (y-axis, ranging 600 to 1100) versus "MAINTENANCE REQUIREMENTS SCHEDULED" (x-axis, ranging 1000 to 1500), with a point labeled (1699, 1054).
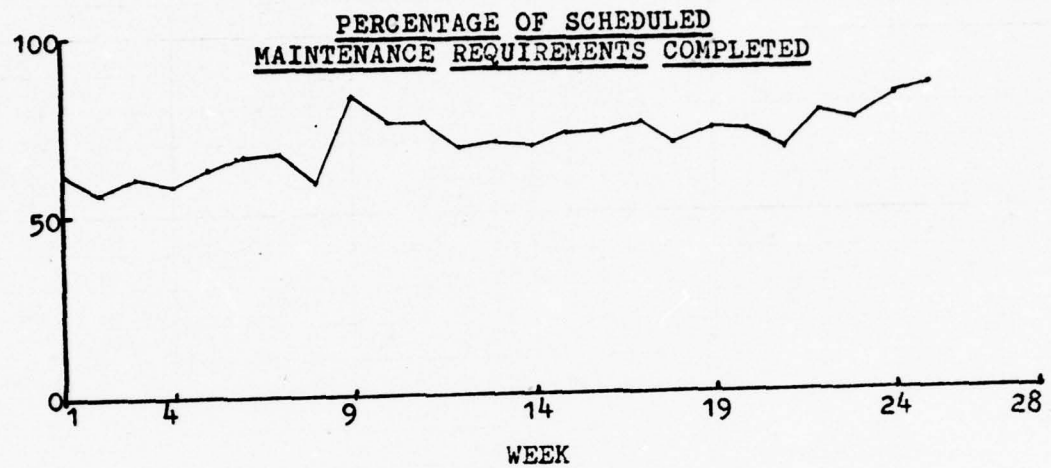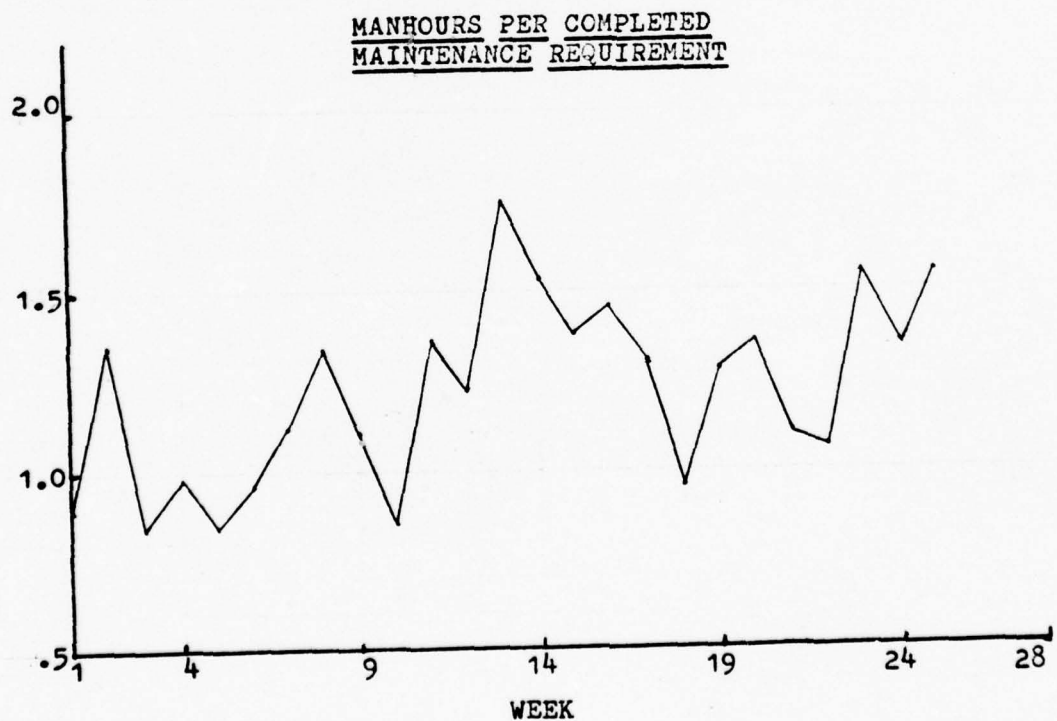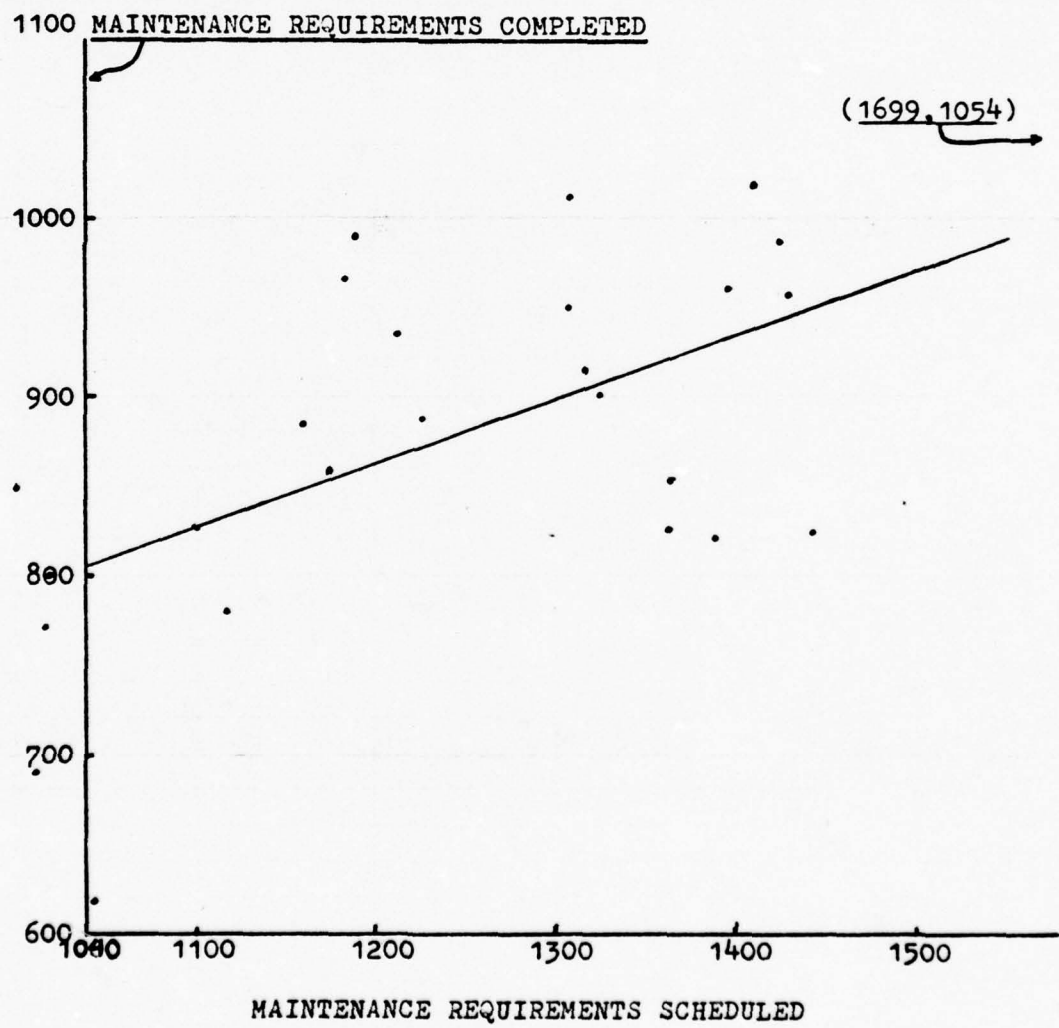
While manhours for preventive maintenance was consistently between 1000 - 1200 manhours per week, manhours for corrective maintenance fluctuated from about five hundred to twenty-seven hundred manhours per week. Of the five separate peaks in manhours for corrective maintenance, four followed at-sea periods of four to seven days during the previous week. This seems to indicate that either Cruiser D was generating more corrective maintenance at sea or that preventive maintenance was being done at the expense of corrective maintenance, forcing more corrective maintenance to be done when the ship returned to port.

During most of the study period, the ratio of manhours for preventive maintenance to those for corrective maintenance was well within the 2:1 to 1:1 (PM:CM) range. Only in two cases where manhours for corrective maintenance increased sharply, and manhours for preventive maintenance remained relatively constant, did the ratio of PM:CM decrease below 1:1.

Starting at about the same level as the other cruisers, Cruiser D's expenditures for maintenance material approximately doubled in the second month then decreased to about the start level for the third, fourth, and fifth months. During the sixth month, expenditures jumped to about two and a half times the start level then decreased again to the start level. These changes in expenditures did not show up as changes in any of the other factors.

Cruiser D's EMRM data for weeks twenty-six, twenty-seven, and twenty-eight were not available.

## F.   GUIDED MISSILE DESTROYER E

During the study period, Guided Missile Destroyer E (DDG E, a test group ship) had an average PM completion rate of 77.5%.  During the first half of the period, the PM completion rate fluctuated from week to week, showing five changes of greater than ten percentage points between two consecutive weeks.  Additionally, the PM completion rate appeared to have an increasing trend, during the first half, increasing from about 55% to 83%.  During the second half of the period, the PM completion rate remained between 80% and 90%.  The PM completion rate was related to the manning level, which, at the start of the period, was fifty-one below the authorized level.  The manning level was increased, so that, by the end of the period, it was only about twenty-two below that authorized.  The changes in the PM completion rate relative to the manning level is shown by the following regression equation:

$$CR_i = 102.164 - 0.6406M_i, \qquad R^2 = .7991 ,$$
$$\quad (6.63) \qquad (.161)$$

where $M_i$ represents the deficit in manning and $CR_i$ represents the estimate of the PM completion rate in the $i^{th}$ month.  The regression was done on a sample with six observations.  The above regression equation would be nonsensical for manning level surpluses; i.e., a

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completion rate greater than 100% would result. The fact that the intercept value (102.164) is greater than 100%, is statistically sound, in that, the estimated standard error was 6.63.

There was evidence of some relationship between the number of PM maintenance requirements scheduled and the number completed. A regression of maintenance requirements completed versus maintenance requirements scheduled gave the following regression equation:

$$C_i = 278.806 + 0.4513S_i, \qquad R^2 = .5527$$
$$\quad\;\; (75.16) \qquad (.08)$$

where $S_i$ represents the number of maintenance requirements scheduled and $C_i$ represents the estimate of the number of maintenance requirements completed in the $i^{th}$ week. This regression was done on a sample having twenty-six observations. The significance of both of the above slope values was proven by the previously presented hypothesis test. There was no relationship between the PM completion rate and maintenance manhours nor manhours per maintenance requirement completion, as was shown by the correlation matrix, Table 8. There appeared to be a very slight increasing trend in manhours for corrective maintenance which tended to cause a similar trend in total maintenance manhours. This was accompanied by a very slight decreasing trend in manhours for preventive maintenance.

At the start of the period, DDG E's expenditures for maintenance material was only slightly less than those of most of the cruisers in

## Table 8.  Correlation Matrix of DDG E's
Maintenance Factors

|         | Sked   | Comp   | CR     | PMMH   | CMMH   | AvPMMH |
|---------|--------|--------|--------|--------|--------|--------|
| Sked    | 1.000  | .743   | -.535  | .596   | .082   | .398   |
| Comp    | .743   | 1.000  | .160   | .266   | .368   | .002   |
| CR      | -.535  | .150   | 1.000  | -.500  | .369   | -.538  |
| PMMH    | .596   | .266   | -.500  | 1.000  | .091   | .960   |
| CMMH    | .082   | .368   | .369   | .091   | 1.000  | .035   |
| AvPMMH  | .398   | .002   | -.538  | .960   | .035   | 1.000  |

in the study.  During the second month, expenditures approximately
doubled, then dropped back to less than one and a half times the starting
level, during the third and fourth months.  After the fourth month,
expenditures increased drastically, up to three times the starting level
in the fifth month; three and a half times that level in the sixth month;
and finally, up to ten times the starting level in the seventh month.
These dramatic changes in expenditures did not show up, to the same
extent, in any of the other maintenance factors.

During the first eight weeks of the study, manhours for preventive
maintenance was reported as being quite a bit higher than during the
rest of the study period (week 1 - 4700 manhours; week 5 - 2000 manhours;
and week 6 - 2700 manhours).  During that time, manhours for corrective
maintenance were relatively low, so that the ratio of manhours for pre-
ventive maintenance to those for corrective maintenance was higher than

# FIGURE 18

## GUIDED MISSILE DESTROYER E
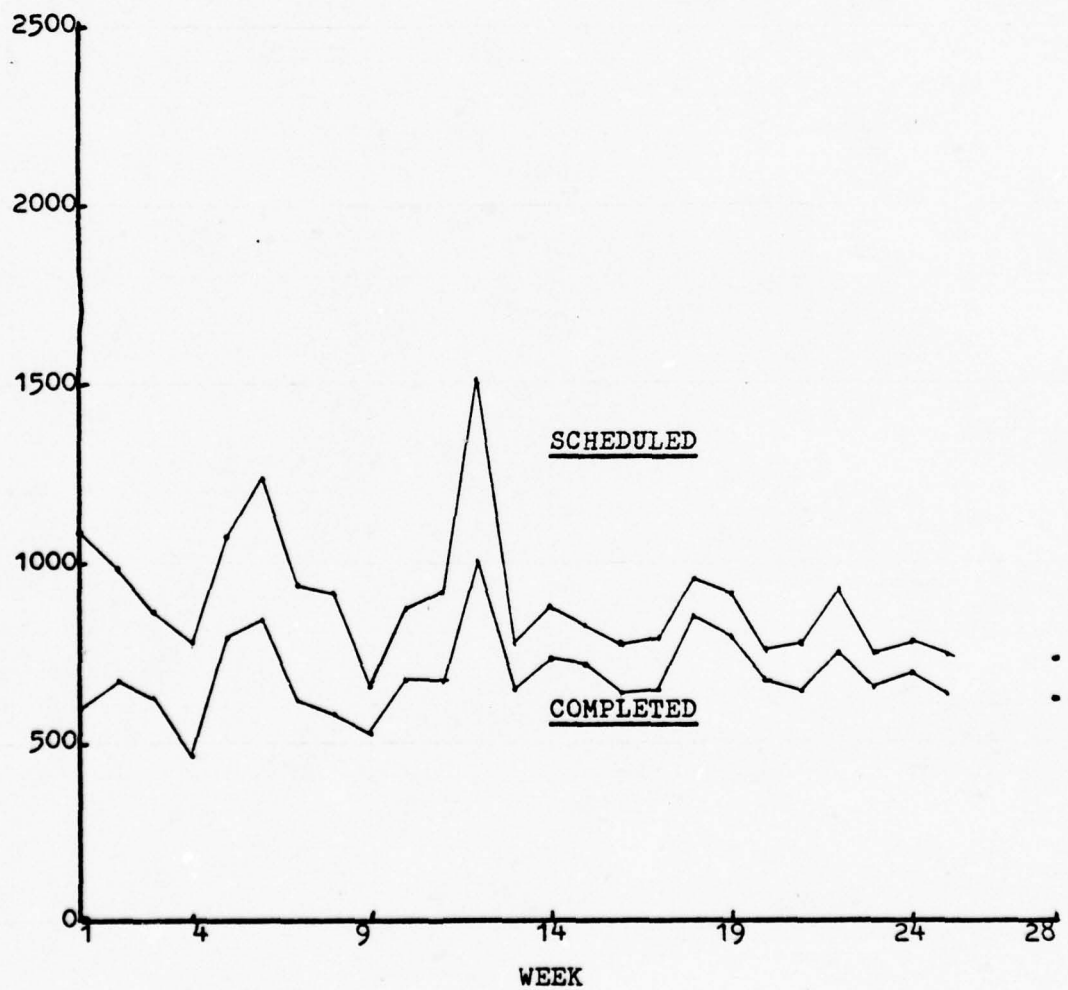
### PREVENTIVE MAINTENANCE
### MAINTENANCE REQUIREMENTS

# FIGURE 19

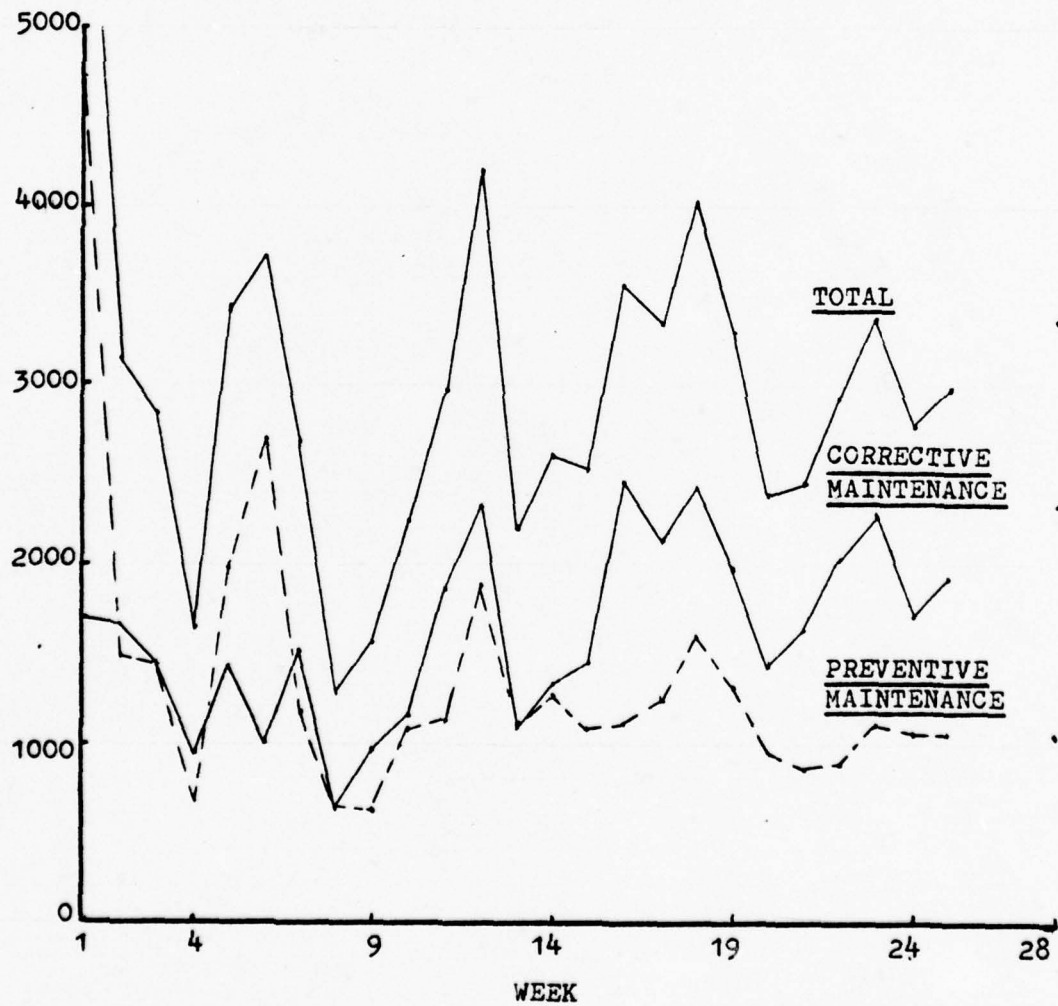## GUIDED MISSILE DESTROYER E

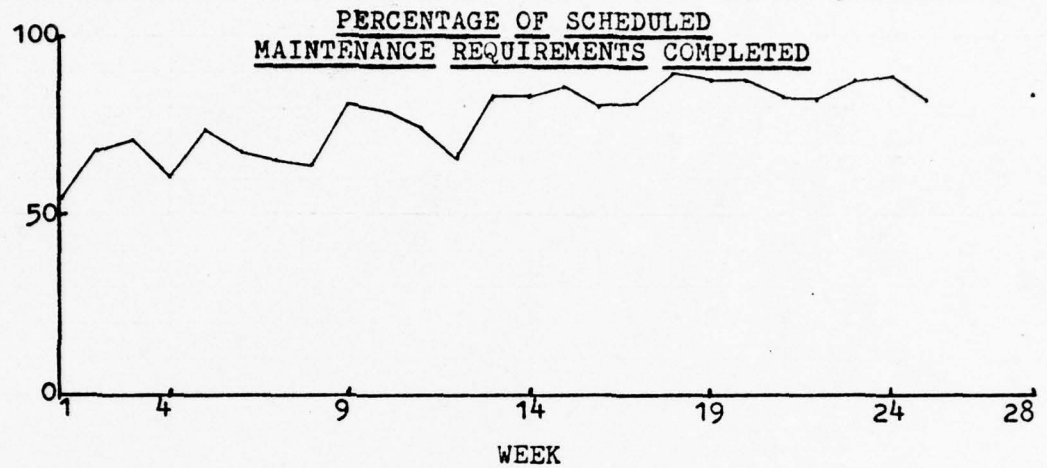### MANHOURS
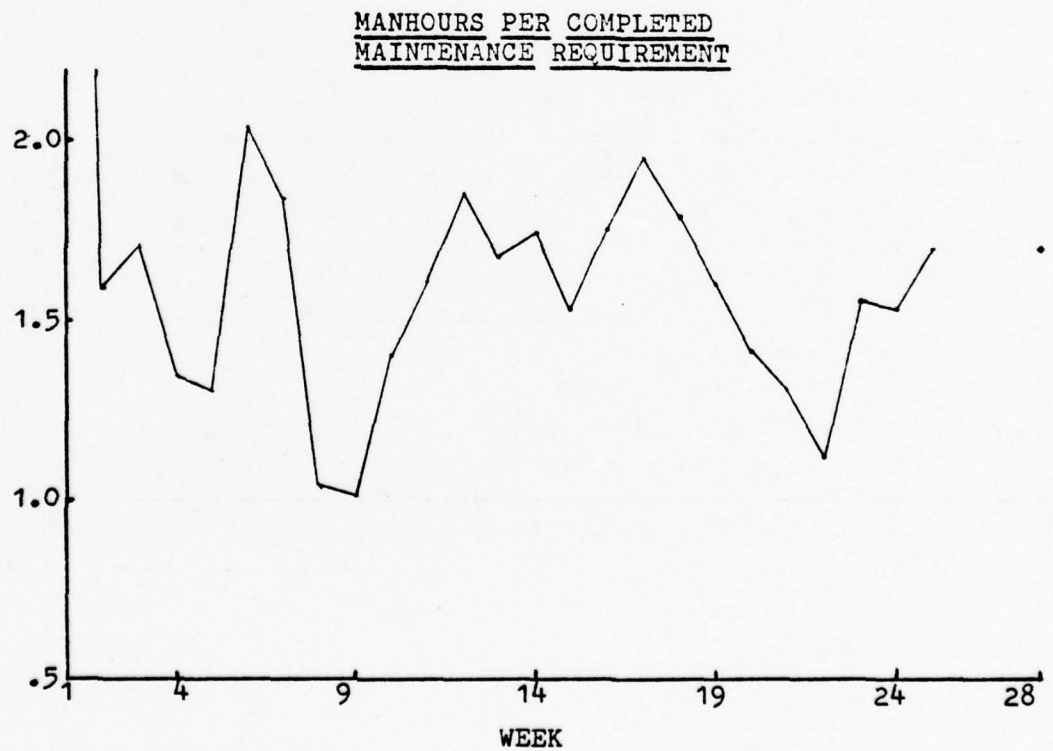
FIGURE 20

GUIDED MISSILE DESTROYER E

PERCENTAGE OF SCHEDULED
MAINTENANCE REQUIREMENTS COMPLETED



WEEK

FIGURE 21

GUIDED MISSILE DESTROYER E

MANHOURS PER COMPLETED
MAINTENANCE REQUIREMENT



WEEK

52

or between 2:1 and 1:1 (PM:CM). After the eighth week, the ratio was always (except for one week, when it was 1:1) below 1:1 (PM:CM), dropping in some cases to lower than 1:2. These changes seem to bear out the previous observation that, as more funds are made available for repair parts, more emphasis was given to corrective maintenance.

DDG E had one extended stay, of twelve weeks, in-port (from the seventh week until the nineteenth week). Any effect of whether the ship was in-port or at-sea, on her maintenance effort, could not be seen in the data. The EMRM data for the twenty-sixth and twenty-seventh weeks were not available.

G. GUIDED MISSILE DESTROYER F

During the test period, Guided Missile Destroyer F (DDG F, a test group ship) had an average PM completion rate of 56.6%. The PM completion rate was very erratic, dipping as low as 36% and reaching approximately 70% on two occasions. On six occasions the completion rate changed by more than ten percentage points, but less than twenty percentage points, between two consecutive weeks. Once, it changed by more than twenty percentage points between consecutive weeks. On several occasions, the PM completion rate dropped when the number of PM maintenance requirements scheduled increased, and vice versa. However, these changes were not consistent enough to establish an inverse relationship.

The ship's manning level changed from month to month. At the start of the study period, DDG F was about twenty-seven below the authorized manning level. This deficit was reduced to twenty-three below authorized manning in the second month but dropped to twenty-nine below in the third month. During the fourth and fifth months, manning improved to fifteen below authorized and six below, respectively. During the sixth month, manning dropped to thirteen below the ship's authorized level. These changes were not reflected by any of the maintenance factors.

The correlation matrix, Table 9, showed that there was no relationship between the PM completion rate and maintenance manhours nor manhours per maintenance requirement completion. From the

Table 9.   Correlation Matrix of DDG F's
Maintenance Factors

|  | Sked | Comp | CR | PMMH | CMMH | AvPMMH |
|---|---|---|---|---|---|---|
| Sked | 1.000 | .596 | -.365 | .155 | .741 | -.306 |
| Comp | .596 | 1.000 | .521 | .300 | .254 | -.408 |
| CR | -.365 | .521 | 1.000 | .131 | -.462 | -.197 |
| PMMH | .155 | .300 | .131 | 1.000 | -.140 | .729 |
| CMMH | .741 | .254 | -.462 | -.140 | 1.000 | -.316 |
| AvPMMH | -.306 | -.408 | -.197 | .729 | -.316 | 1.000 |

graphs, it appeared that there was some relationship between the number of PM maintenance requirement scheduled and the number completed. However, the regression of these two factors gave a regression equation with a coefficient of determination ($R^2$) of only .3553. During the period, between the eleventh week and the eighteenth week, this relationship obviously did not hold. Even when the data from this eight week period were excluded, the $R^2$ was only improved to .4367. In either case, only a weak relationship was indicated.

DDG F spent extended periods of time in-port. During the eighteen week period, from the third week through the twentieth week, she spent only fourteen days at-sea. This period ended with an eight week period in which only one day per week, was spent at-sea, during the last two weeks. During the eight week portion of the eighteen week in-port period, the manhours for corrective maintenance increased sharply and manhours for preventive maintenance continued at a slightly lower rate. During the early part of the study period, when the ship alternated between being in-port continuously (for a week) to being at-sea for two or three days per week, the manhours per maintenance requirement completion rose to over 2.5 manhours per completion (compared to the average of 1.85).

DDG F started the study period with expenditures for maintenance material, about twice the starting level of the cruiser and the other guided missile destroyers. During the second month, expenditures

FIGURE 22

GUIDED MISSILE DESTROYER F

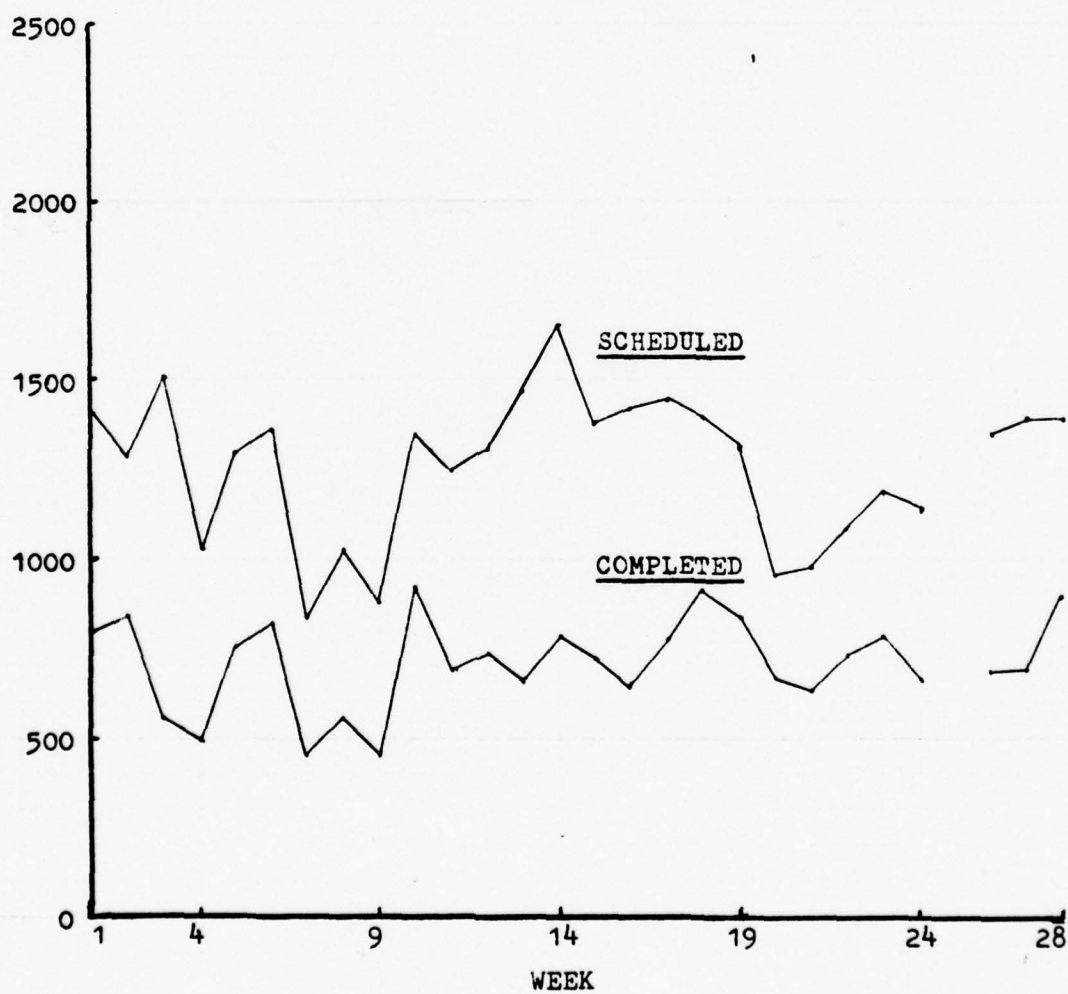PREVENTIVE MAINTENANCE
MAINTENANCE REQUIREMENTS

# FIGURE 23

## GUIDED MISSILE DESTROYER F

### MANHOURS
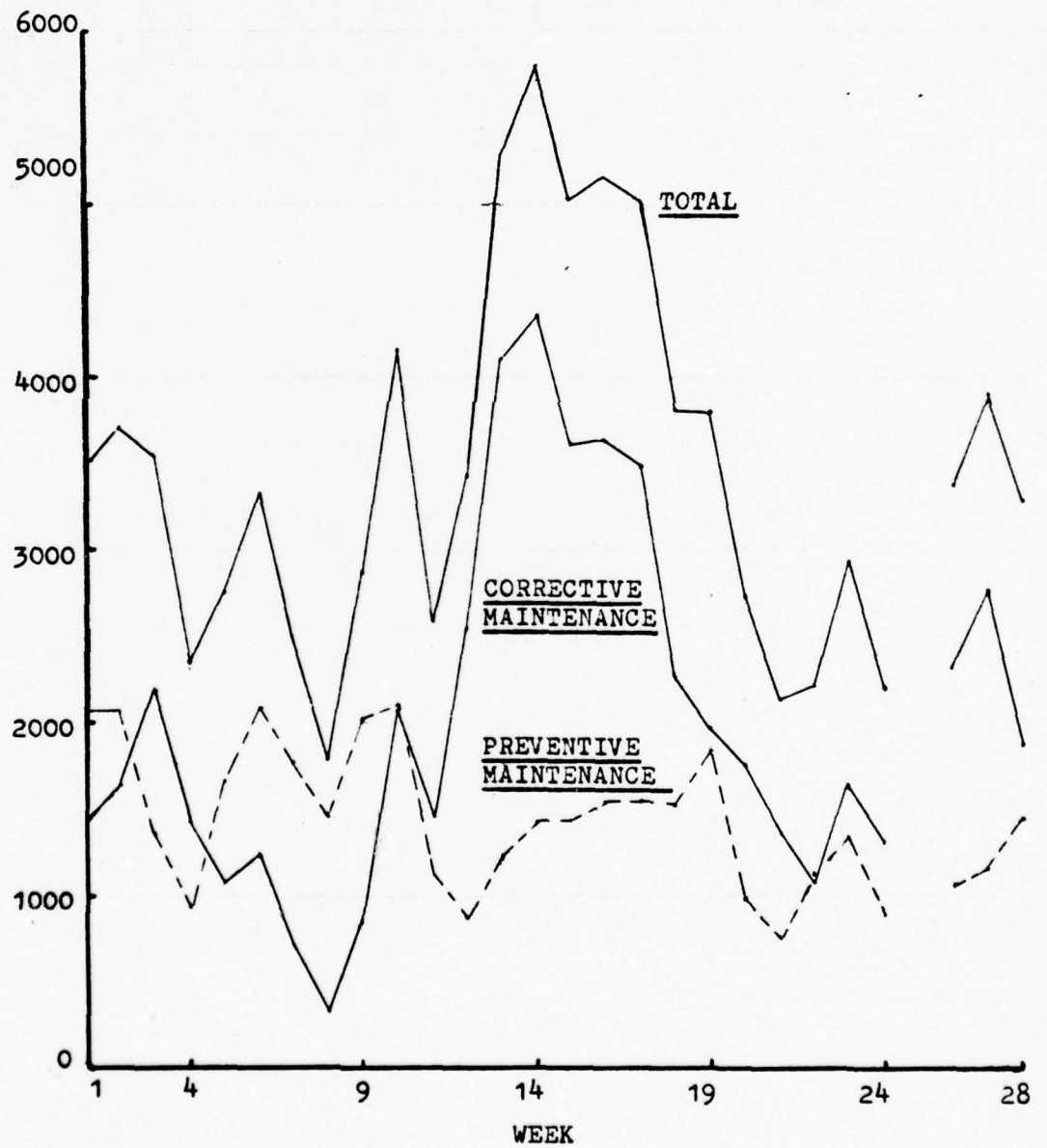
## FIGURE 24

### GUIDED MISSILE DESTROYER F

#### PERCENTAGE OF SCHEDULED
#### MAINTENANCE REQUIREMENTS COMPLETED



WEEK

## FIGURE 25

### GUIDED MISSILE DESTROYER F
### MANHOURS PER COMPLETED
### MAINTENANCE REQUIREMENT



* Denotes value exceeds 2.5
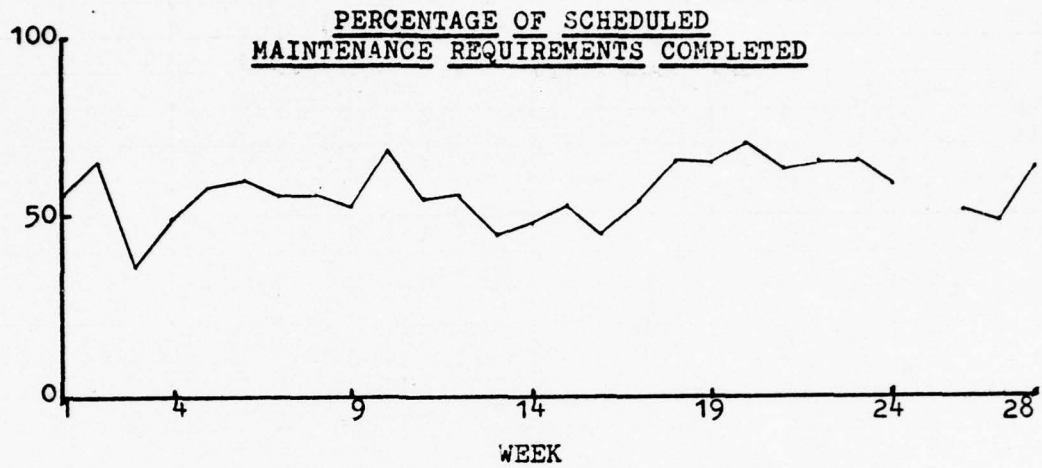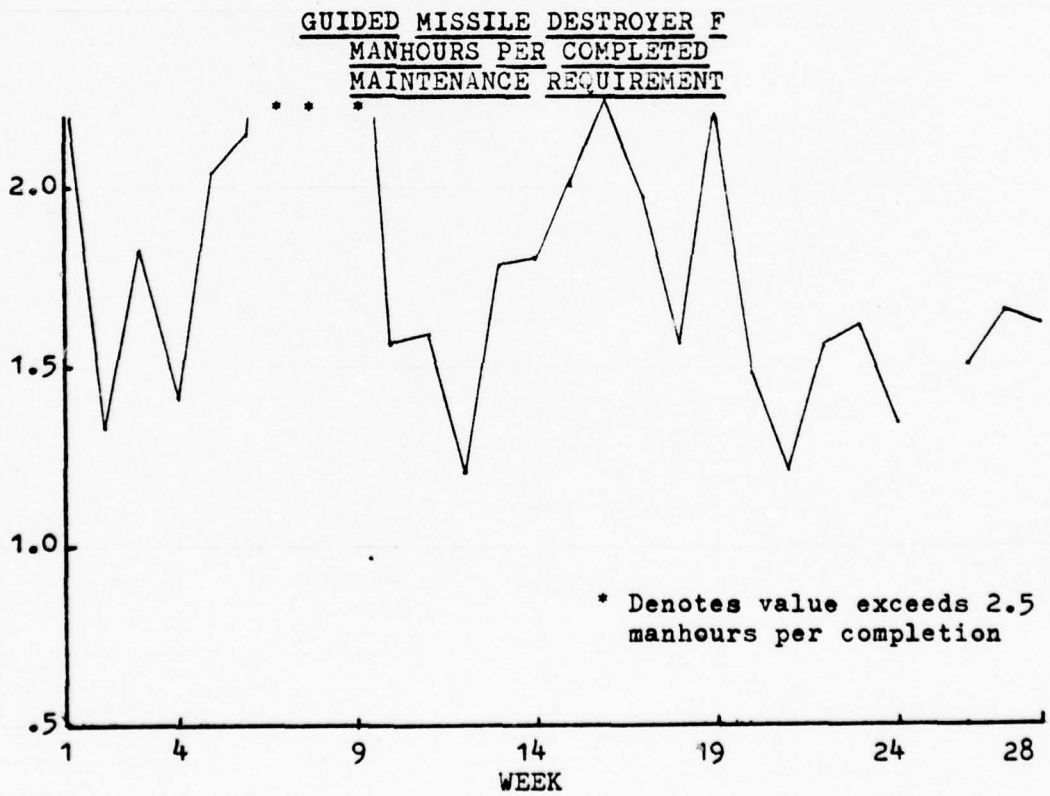  manhours per completion

WEEK

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dropped to about the same as the start level of the other ships. During the third, fourth, and fifth month, expenditures were about three and a half times the start level of the other ships. Expenditures rose in the sixth month (to four times the start level), then in the seventh month to ten times the start level.

During the first four months, the changes in the number of manhours for corrective maintenance closely approximated the changes in expenditures for repair parts. However, in the fifth, sixth, and seventh months, while expenditures increased exorbitantly, manhours for corrective maintenance dropped sharply. During the first ten weeks of the study, the ratio of manhours for preventive maintenance to manhours for corrective maintenance was close to the 2:1 to 1:1 (PM:CM) range. Then, as the manhours for corrective maintenance rose sharply, at the time when expenditures rose, the ratio decreased to as low as 1:2.7 (PM:CM). At the end of the period, the ratio was about 1:2. This observation seems to substantiate the proposition that, more emphasis was shifted to corrective maintenance, when additional funds were available for repair parts.

The EMRM data for the twenty-fifth week were not available.

H.   GUIDED MISSILE DESTROYER G

During the period being studied, Guided Missile Destroyer G (DDG G, a control group ship) had an average PM completion rate of

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74. 8%.  The PM completion rate was in the range of 70% to 80% except

twice when it dropped to 60% and three times when it went as high as

86%.  Though the PM completion rate was quite steady, it did change

by as much as ten percentage points between consecutive weeks on four

occasions.  All four of these changes were during the first ten weeks

of the study.

The correlation matrix, Table 10, showed that there was no

relationship between the PM completion rate and maintenance manhours

nor manhours per maintenance requirement completion.   Though both

Table 10.  Correlation Matrix of DDG G's
Maintenance Factors

|        | Sked   | Comp   | CR     | PMMH   | CMMH   | AvPMMH |
|--------|--------|--------|--------|--------|--------|--------|
| Sked   | 1. 000 | . 962  | . 140  | . 824  | . 348  | -. 084 |
| Comp   | . 962  | 1. 000 | . 403  | . 838  | . 292  | -. 127 |
| CR     | . 140  | . 403  | 1. 000 | .292   | -. 100 | -. 147 |
| PMMH   | . 824  | . 838  | .292   | 1. 000 | .519   | . 432  |
| CMMH   | . 348  | . 282  | -. 100 | . 519  | 1. 000 | . 488  |
| AvPMMH | -. 084 | -. 127 | -. 147 | . 432  | . 488  | 1. 000 |

the PM completion rate and the manhours per maintenance require-

ment completion showed slight increasing trends, particularly after

the ninth week, the PM completion rate was much more stable than

manhours per completion.

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The stability of the PM completion rate was further demonstrated by the high degree of correlation between PM maintenance requirement completed versus the number scheduled. The following regression equation shows this relationship:

$$C_i = -49.46 + .7974S_i, \qquad R^2 = .9259$$
$$(56.7) \qquad (.049)$$

where $S_i$ represents the number of PM maintenance requirement scheduled and $C_i$ is the estimate of the number completed during the $i^{th}$ week. This regression was done with a sample of size twenty-three. The slope value's significance was proven by hypothesis testing.

At the start of the period, DDG G was manning to approximately thirty-seven below her authorized manning level. During the second and third months, this deficit was reduced to about thirteen below the authorized level. During the fourth month manning dropped to twenty-four below the authorized level, but increased back to only nine below in the fifth month. In the sixth month the manning level dropped again to nineteen below authorized manning. During the nine week period, starting with the fourteenth week, manhours per maintenance requirement completion fluctuated radically. The most probable cause for these changes was the changes in the manning level. Between the third and the fourth months, the manning level dropped by nine personnel, then increased by fifteen personnel the next month.

During this nine week period, manhours for corrective maintenance also fluctuated radically, with sharp increases. During seven of these

FIGURE 26

GUIDED MISSILE DESTROYER G
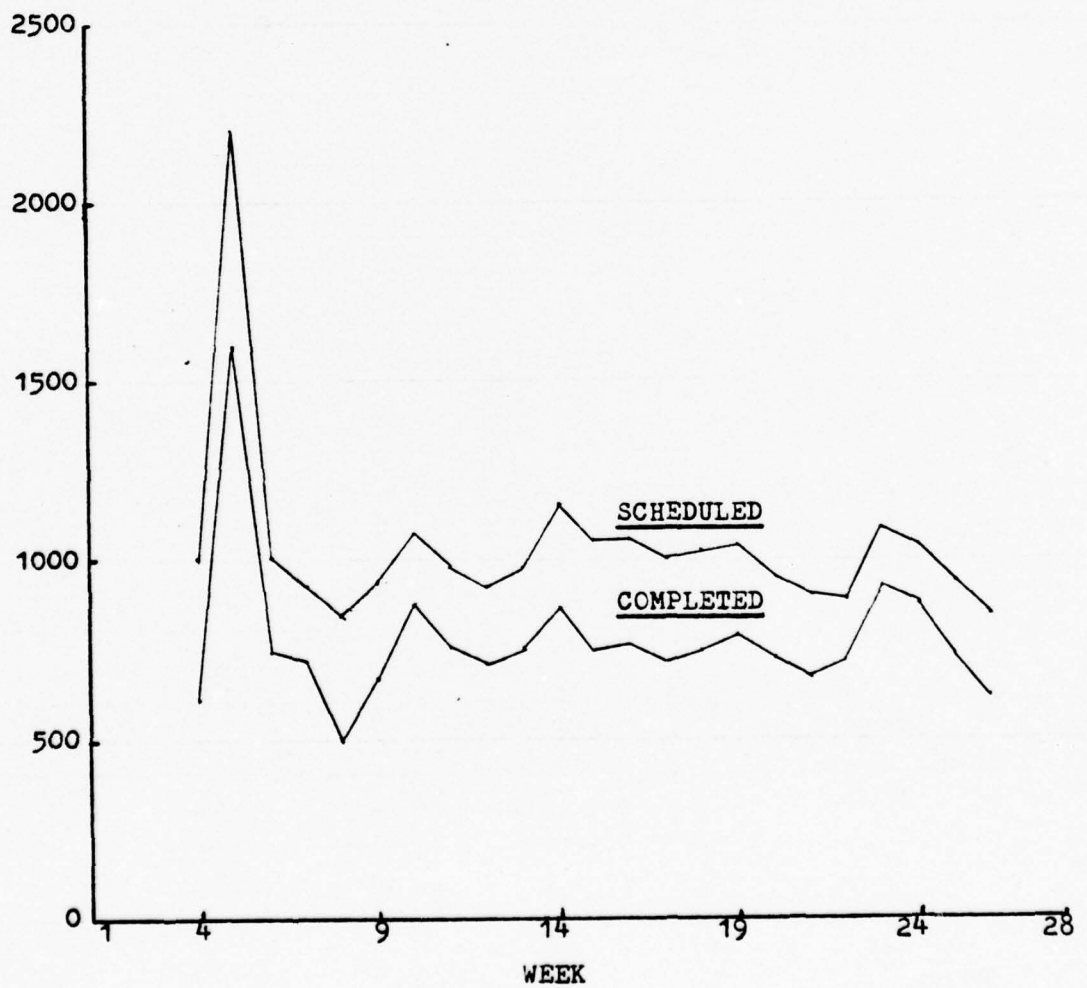
PREVENTIVE MAINTENANCE
MAINTENANCE REQUIREMENTS

# FIGURE 27
## GUIDED MISSILE DESTROYER G
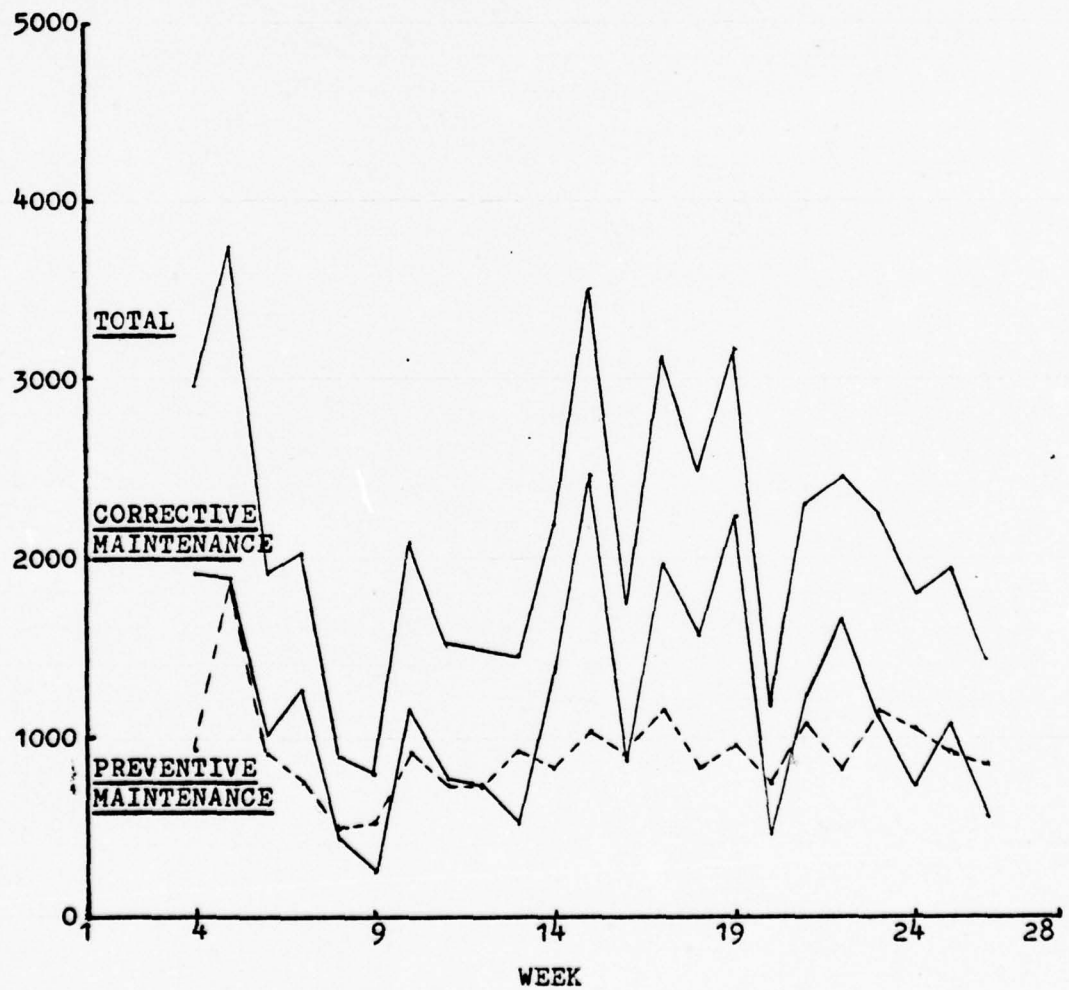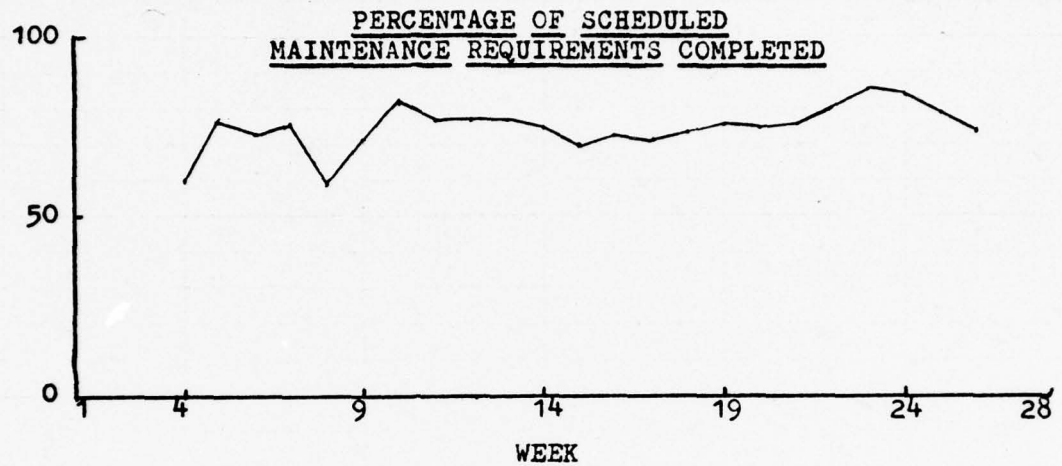
### MANHOURS

# FIGURE 28
## GUIDED MISSILE DESTROYER G

### PERCENTAGE OF SCHEDULED
### MAINTENANCE REQUIREMENTS COMPLETED



WEEK

# FIGURE 29
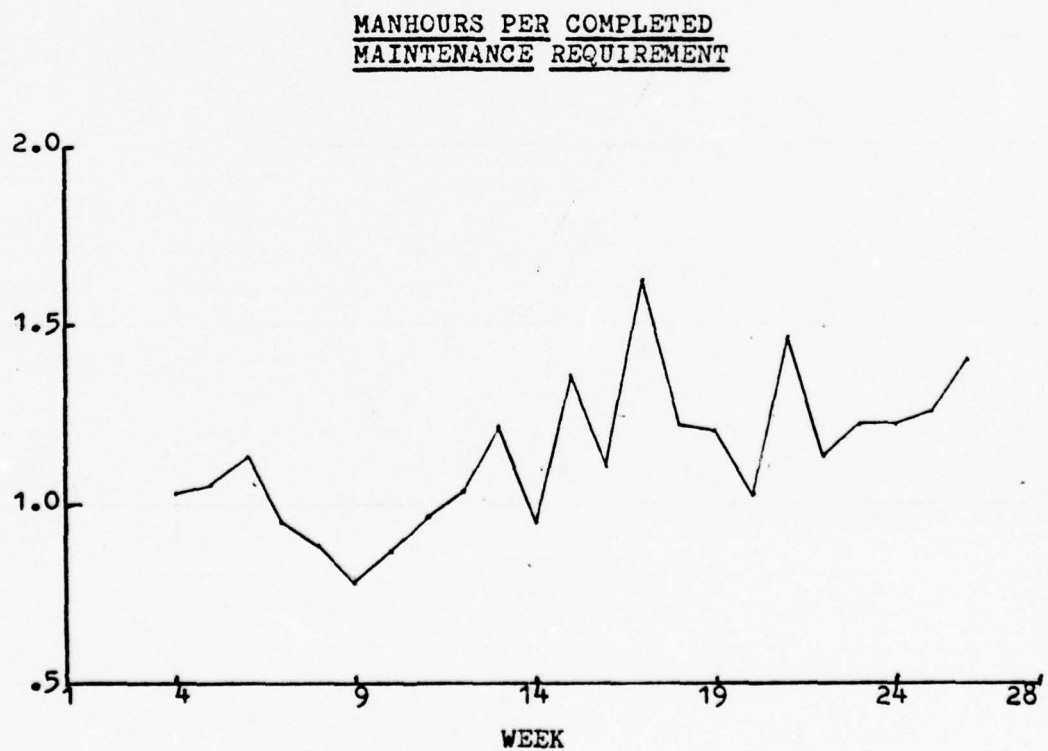## GUIDED MISSILE DESTROYER G

### MANHOURS PER COMPLETED
### MAINTENANCE REQUIREMENT



WEEK

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nine weeks, the ratio of manhours for preventive maintenance to manhours for corrective maintenance dropped sharply out of the 2:1 to 1:1 (PM:CM) range, dropping on some occasions to as low as 1:2 (PM:CM). None of the data offered an explanation for these changes, except for possible dependence of manhours for corrective maintenance on the ship's manning level. Possibly, the loss of critical personnel forced less qualified personnel to do the corrective maintenance. There were not enough observations of the ship's manning level, due to the short duration of this transitory period, to check for dependence between these factors using regression analysis.

Changes in the maintenance factors which were due to the ship's operating schedule were not consistent throughout the period. There was some evidence that more of the PM maintenance requirements were scheduled when the ship was in-port than when at-sea. After about the tenth week, manhours for preventive maintenance were applied uniformly at a rate of about 900-1070 manhours per week. During the ten week period, from the twelfth week through the twenty-first week, changes in manhours for corrective maintenance seemed to follow changes in the operating schedule. It was not possible to do a meaningful regression on this data, since eight of the ten observations were with either two days or seven days per week in-port. During this ten week period, manhours for corrective maintenance went up when the ship spent more days in-port.

At the start of the period, DDG G's expenditures for maintenance material was slightly higher than the starting level of the cruisers and DDG E. During the second, third, fourth, and fifth months, expenditures were decreasing so that by the fifth month, they were slightly below the average starting level. Expenditures continued to decrease, reaching about one half the average starting level during the sixth month. They then increased during the seventh month to slightly less than the start level of the cruisers and DDG E. No changes in the maintenance factors were recognized as corresponding to the changes in expenditures for repair parts.

The EMRM data for the first three weeks and the last two weeks of the study period were not available.

I. GUIDED MISSILE DESTROYER H

During the study period, Guided Missile Destroyer H (DDG H, a control group ship) had an average PM completion rate of 62.5%. The PM completion rate fluctuated from week to week, but remained within the range of 55% - 68% except twice when it was as high as 73%. Only on two occasions did the completion rate change by more than ten percentage points between two consecutive weeks.

The correlation matrix, Table 11, showed no evidence of dependence of PM completion rate on maintenance manhours or manhours per maintenance requirement completion. The regression of maintenance

Table 11.  Correlation Matrix of DDG H's
Maintenance Factors

|         | Sked   | Comp   | CR     | PMMH   | CMMH  | AvPMMH |
|---------|--------|--------|--------|--------|-------|--------|
| Sked    | 1.000  | .824   | -.126  | .460   | .213  | .002   |
| Comp    | .824   | 1.000  | .456   | .531   | .279  | -.046  |
| CR      | -.126  | .456   | 1.000  | .184   | .154  | -.115  |
| PMMH    | .460   | .531   | .184   | 1.000  | .327  | .820   |
| CMMH    | .213   | .279   | .154   | .327   | 1.000 | .174   |
| AvPMMH  | .002   | -.046  | -.115  | .820   | .174  | 1.000  |

requirements completed versus maintenance requirements scheduled
revealed some correlation between these factors.  The resulting regres-
sion equation was

$$C_i = 104.464 + .5357 S_i, \quad R^2 = .6206$$
$$(101.37) \quad (.08)$$

where $S_i$ represents the number of maintenance requirements scheduled
and $C_i$ is the estimate of the number of maintenance requirements
completed during the $i^{th}$ week.  The regression was done with a sample
having twenty-six observations.  The slope value's significance was
proved by hypothesis testing.

DDG H started the test period manned at forty-five below her
authorized manning level.  This condition steadily improved so that,
by the end of the test period, she was manned to six over the authorized
level.  This improving trend in manning was not discernable in changes
in any of the maintenance factors.

# FIGURE 30

## GUIDED MISSILE DESTROYER H

### PREVENTIVE MAINTENANCE
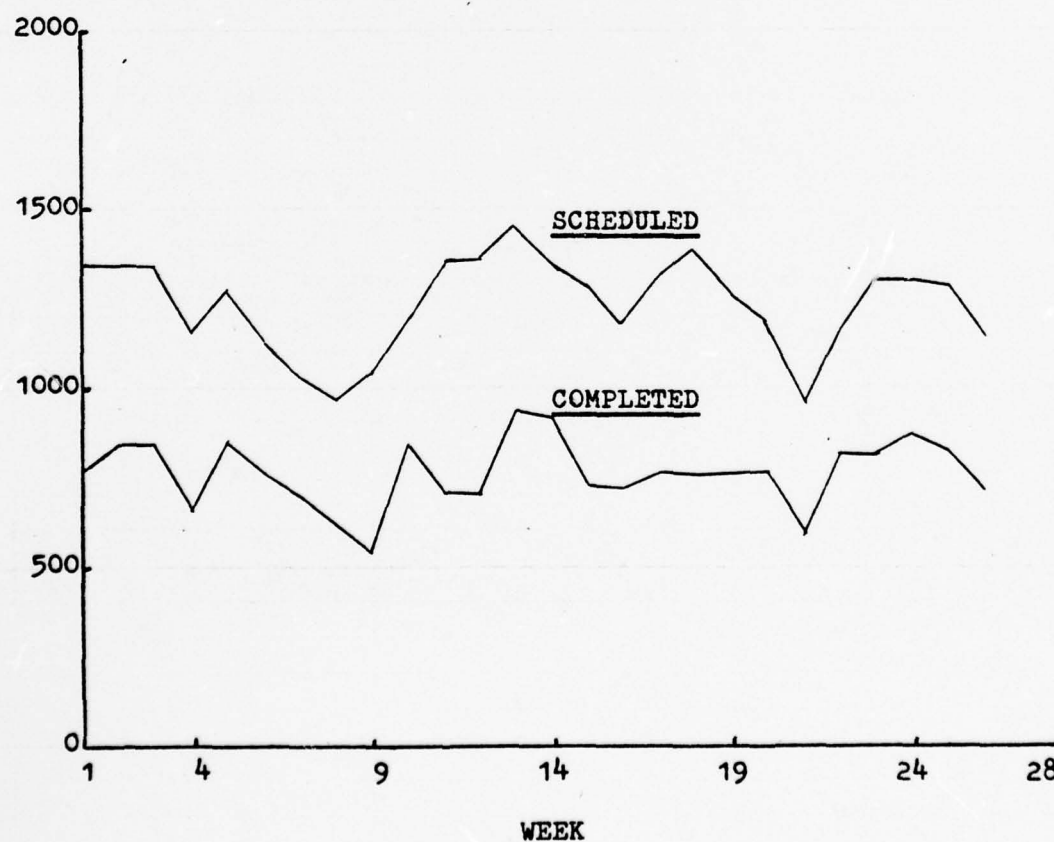### MAINTENANCE REQUIREMENTS

# FIGURE 31

## GUIDED MISSILE DESTROYER H

### MANHOURS
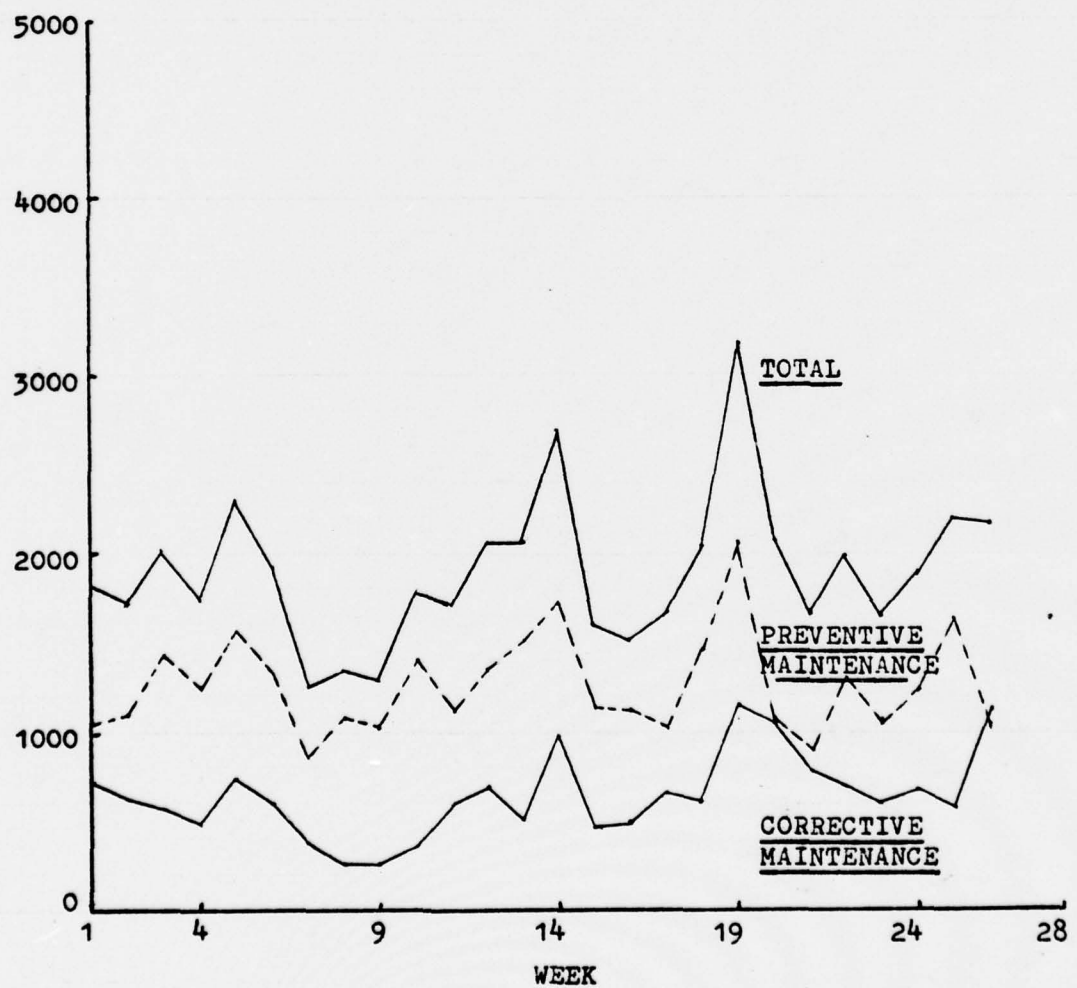
## FIGURE 32

### GUIDED MISSILE DESTROYER H

#### PERCENTAGE OF SCHEDULED
#### MAINTENANCE REQUIREMENTS COMPLETED



## FIGURE 33

### GUIDED MISSILE DESTROYER H

#### MANHOURS PER COMPLETED
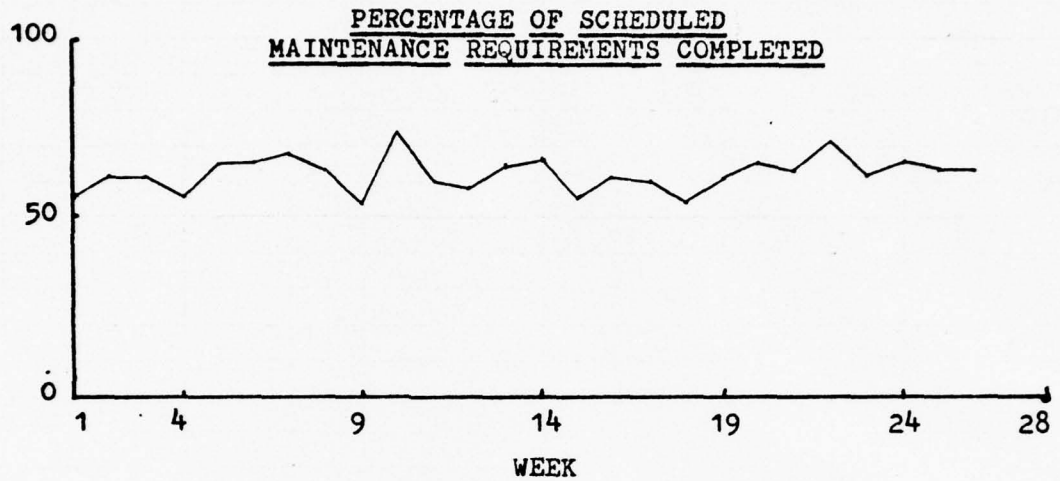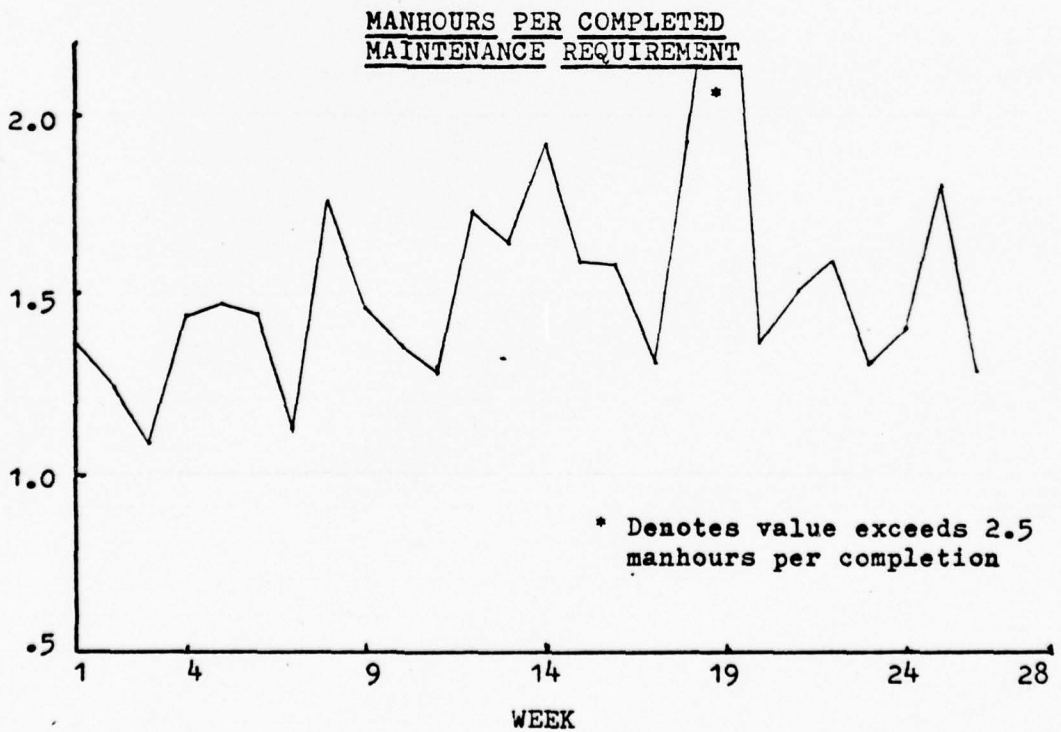#### MAINTENANCE REQUIREMENT



\* Denotes value exceeds 2.5
manhours per completion

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DDG H had one in-port period of nine weeks, from the seventh week to the fifteenth week, and another three week in-port period just before the end of the test period. It was not possible to detect changes in the maintenance factors which could be attributed to the ship's operational schedule.

At the start of the period, DDG H's level of expenditures for maintenance material was about one half of the starting levels of the cruisers and DDG E. During the second month, expenditures rose to slightly less than the starting level of the other ships mentioned above. During the third, fourth, and fifth months, they were approximately the same as the start level of DDG H. During the sixth and seventh months, expenditures climbed so that during the seventh month, they were slightly higher than the starting level of the other ships.

The only implication shown by the expenditures for repair parts was that of the ratio of manhours for preventive maintenance to manhours for corrective maintenance. This implication could only be drawn by comparing this information with similar information from the other ships. DDG H's expenditures were low throughout the entire period. Her ratio of manhours for preventive maintenance to manhours for corrective maintenance was consistently within the 2:1 to 1:1 (PM:CM) range or above it.

The level of maintenance in DDG H appeared to be lower than in the other guided missile destroyers. This was evident in the number

of maintenance requirements scheduled and completed and in the manhours utilized for preventive and corrective maintenance.

The EMRM data for the last two weeks of the period were not available.

The analytical results from this chapter, which are more prevalent from ship to ship, are summarized in the following chapter. Additionally, conclusions, drawn from the comparison of the accomplishment of maintenance on different ships, are presented in that chapter.

## VI. FINDINGS AND CONCLUSIONS

In the analysis chapter of this paper, several observations were made concerning interdependencies between the factors of maintenance being studied. Where it was appropriate, regression analysis was used to measure the strength of these relationships. Table 12 is a list of the regression equations, which represented the relationships with coefficients of determination $(R^2)$ high enough to be considered significant.

Table 12. Regression Equations for Selected Maintenance Factors

| Cruiser A | $Y_i = 1.42 - 0.013M_i,$ | $R^2 = .8235$ | $n = 6$ |
|-----------|--------------------------|---------------|---------|
| Cruiser B | $C_i = -163.56 + .73S_i$ | $R^2 = .7479$ | $n \doteq 27$ |
| Cruiser C | $C_i = 249.04 + .56S_i,$ | $R^2 = .4542$ | $n = 28$ |

Using selected data

| | $C_i = 46.098 + .77S_i,$ | $R^2 = .8299$ | $n = 16$ |
|-------|--------------------------|---------------|----------|
| DDG E | $CR_i = 102.16 - .64M_i,$ | $R^2 = .7991$ | $n = 6$ |
| | $C_i = 278.81 + .45S_i,$ | $R^2 = .5527$ | $n = 26$ |
| DDG G | $C_i = -49.46 + .80S_i,$ | $R^2 = .9259$ | $n = 23$ |
| DDG H | $C_i = 104.46 + .54S_i,$ | $R^2 = .6206$ | $n = 26$ |

where $Y_i$ is the estimate of the manhours per maintenance require-ment completion, in the $i^{th}$ month

$M_i$ is the manning deficit for the $i^{th}$ month

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$C_i$ is the estimate of the number of maintenance requirements completed in the $i^{th}$ week

$S_i$ is the number of maintenance requirements scheduled in the $i^{th}$ week

$CR_i$ is the estimate of the PM completion rate in the $i^{th}$ month

Though it is appealing to have the intercept value, in a regression equation, closely approximate its theoretical (true) value, the slope of the regression line may not be constant throughout the range of all possible values of the data, causing the apparent (regression equation) intercept to be different than the theoretical intercept. Another cause of deviation of the apparent intercept from its theoretical value is the random character of the sample from which the regression equation was derived.

Table 13 is a list of average PM completion rates for the study ships. These averages were for the entire study period

Table 13. Average PM Completion
Rates for EMRM Ships

| Cruiser A | 59.7% | DDG E | 77.5% |
| Cruiser A | 61.6% | DDG F | 56.6% |
| Cruiser C | 74.9% | DDG G | 74.8% |
| Cruiser D | 70.6% | DDG H | 62.5% |

Of the regression equations, the regression of the number of maintenance requirements completed versus the number scheduled appeared more frequently than the other regressions. The regression

of the number of maintenance requirements completed versus the
number scheduled, by ship, was used to provide insight into how
maintenance requirement accomplishment changed as more, or fewer,
maintenance requirements were scheduled each week. The slopes of
the regression lines give a measure of how many more maintenance
requirements, the ship completed for each additional maintenance
requirement scheduled. This measure is quite significant when com-
pared to the average PM completion rate. When the slope of the regres-
sion line was greater than the average PM completion rate, it indicated
a tendency for the ship to improve its PM completion rate as more
maintenance requirements were scheduled. Having the slope of the
regression line less than the average PM completion rate indicated a
tendency for the PM completion rate to go down as more maintenance
requirements were scheduled. Applying this criterion, the data indicated
that DDG E and DDG H tended to complete fewer maintenance require-
ments as more were scheduled, while Cruiser B and DDG G tended to
complete more maintenance requirements as more were scheduled. For
the whole period, Cruiser C showed the tendency to complete fewer
maintenance requirements as more were scheduled. When the data
for the twelve week period, while her maintenance activity showed
greater instability, was excluded, Cruiser C showed the tendency to
complete slightly more maintenance requirements as more were
scheduled.

The PM completion rate was intended to be one of the principal measures of performance in the accomplishment of preventive maintenance. It was found that the PM completion rate did not correlate well with the other factors which were also indicators of how well this maintenance was accomplished. However, in the data for only one ship, DDG E, a high degree of correlation was found between the PM completion rate and the ship's manning deficits.

The analysis showed that the accomplishment of maintenance in three other ships was affected by their manning levels. In Cruiser A, manning deficits were inversely related to manhours per maintenance requirement completion. The correlation matrix, Table 14, showed a high degree of correlation between total maintenance manhours and manhours per maintenance requirement completion in the control group cruisers. Also, in DDG G, there were indications of the relationship between the manning level and manhours per maintenance requirement completion. During a nine week period, when the manning level

Table 14. Correlation Matrix of the Control
Group Cruisers' Maintenance Factors

|         | Sked   | Comp   | TMH    | PMMH   | CMMH   | AvPMMH |
|---------|--------|--------|--------|--------|--------|--------|
| Sked    | 1.000  | .664   | .090   | .174   | .029   | -.045  |
| Comp    | .664   | 1.000  | .128   | .209   | .066   | -.122  |
| TMH     | .090   | .128   | 1.000  | .941   | .975   | .916   |
| PMMH    | .174   | .209   | .941   | 1.000  | .843   | .943   |
| CMMH    | .029   | .066   | .975   | .843   | 1.000  | .841   |
| AvPMMH  | -.045  | -.122  | .916   | .942   | .841   | 1.000  |

(1) TMH is the abbreviation for total maintenance manhours

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dropped by nine persons then increased by fifteen, manhours per maintenance requirement completion fluctuated more radically than during the rest of the period. Finally, the effects of manning level changes in Cruiser C's accomplishment of maintenance must be inferred. A regression was done for Maintenance requirements completed versus those scheduled by Cruiser C, for the whole period. The $R^2$ of this equation was .4542. When a regression was done on the same factors, excluding the data from a twelve week period when the manning level was unstable, the $R^2$ improved to .8299.

One of the most consistent relationships found in this research was between expenditures for maintenance material and the ratio of manhours for preventive maintenance to manhours for corrective maintenance. In four of the ships (all test group ships), as expenditures were increased, the ratio of manhours for preventive mainten- ance to manhours for corrective maintenance decreased. This relationship showed that as more funds were available for repair parts, the ships in the test group placed more emphasis on corrective maintenance. Additionally, when Cruiser A and Cruiser B experienced decreases in expenditures, manhours for preventive maintenance dropped. This seemed to indicate that after the ships had established more emphasis on the accomplishment of corrective maintenance, time was required in which to redirect their aims.

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Changes in the maintenance factors, caused by the ships' employ-

ment schedule, were most difficult to identify and analyze. This

was due, mostly, to the lack of consistency of the dependences of the

maintenance factors on the ships' operating schedule. In some cases,

certain relationships seemed to hold during several weeks periods,

but were not at all apparent during the rest of the study period. Addi-

tionally, the relationships did not always hold from ship to ship.

The dependency of manhours per maintenance requirement comple-

tion on the ship's schedule appeared more frequently than the dependency

of any of the other maintenance factors, on the schedule. In six of the

eight ships, manhours per maintenance requirement completion tended

to increase while the ship was in-port and to decrease when at-sea.

This indicated that the more time (manhour) consuming maintenance

requirements were done in-port and maintenance requirements done

at-sea were mostly routine ones. Occasionally, peaks in manhours

per maintenance requirement completion were generated while the

ship was at-sea, indicating that some of the more complicated main-

tenance requirements were done at-sea. There were two other indica-

tions of higher levels of maintenance activity when the ships were

in-port. Six of the eight ships showed higher levels of maintenance

requirements scheduled and completed when the ships were in-port.

While four of the ships showed higher manhours for preventive main-

tenance while in-port, two showed slightly higher manhours for

preventive maintenance while at-sea and the remaining two ships showed no trend.  There were also indications of more maintenance activity, in general, while the ships were in-port, as evidenced by higher total maintenance manhours (three ships) and higher manhours for corrective maintenance (two ships) while the ships were in-port.

During the study period, six of the eight study ships had extended in-port periods of six weeks or longer.  Of these, one had a thirteen week in-port period and another spent sixteen weeks in-port at one time.

During the week of Christmas 1975, there was a significant drop in maintenance activity on all of the ships.  All were in-port and had fewer maintenance requirements scheduled and completed as well as manhours expended for maintenance (total, preventive, and corrective).

One of the purposes of the Equipment Maintenance and Related Maintenance Project was to study the impact of additional funding for maintenance material on the accomplishment of shipboard maintenance. Since the EMRM Project was a principal source of data for this research, it seemed appropriate to perform a test to see if there was a difference in the performance of the test group ships and that of the control group ships.

For this test, the following procedure was used.

(1) For each ship, compute

(a) Average Maintenance Requirements Scheduled, per week;

(b) Average Maintenance Requirements Completed, per week;

(c) Average Manhours for Preventive Maintenance, per week;

(d) Average Manhours for Corrective Maintenance, per week; and

(e) Average Manhours per CM Maintenance Action Completed, per week.

(2) For cruisers and for guided missile destroyers, compute the mean for (1a) through (1e); e.g., Average Maintenance Requirements Scheduled per week for cruisers.

(3) For each ship, subtract the appropriate mean (computed in step 2) from the values of (1a) through (1e). (This gives difference from the mean.)

(4) For each ship, divide the difference from the mean (computed in step 3) by its respective mean (from step 2). (This gives the fractional difference from its mean, of each of the values of (1a) through (1e).)

(5) Find the means of the fractional differences (from step 4) and the sample variances for the test group ships and for the control group ships.

(6) The means and sample variances (from step 5) were used to test the hypothesis:

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$$H_o : \overline{X}_t - \overline{X}_c = 0$$

$$H_1 : \overline{X}_t - \overline{X}_c \neq 0$$

where $\overline{X}_t$ represents the test group sample mean and $\overline{X}_c$ represents the
control group sample mean.   The test statistic was

$$\frac{(\overline{X}_t - \overline{X}_c)}{S_{t-c}} .$$

This test statistic was then used to define the test:

$$IF \quad \frac{\overline{X}_t - \overline{X}_c}{S_{t-c}} > 2.323, \quad Reject \ H_o$$

where the value, 2.323, defines the upper limit of the acceptance

region and is obtained from the normal probability tables using a level

of confidence of 0.01.  $S_{t-c}$ is the combined sample variance of

$(\overline{X}_t - \overline{X}_c)$ and was computed using the following equation:

$$S^2_{t-c} = \frac{S^2_t}{n_t} + \frac{S^2_c}{n_c} .$$

The following values were computed during previous steps and were

used in computing the test statistic:

| | | | | |
|---|---|---|---|---|
| $\overline{X}_t$ | = | .13815 | $\overline{X}_c$ | = -.1128 |
| $S^2_t$ | = | .02892 | $S^2_c$ | = .02618 |
| $S_{t-c}$ | = | .05249 | | |

Using the above values, the test statistic was 4.7813.   This value

clearly exceeded the upper limit (2.323) of the acceptance region.

Therefore, the null hypothesis, $H_o$, was rejected.   This implied that

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the statement, "The mean of the test group ships is greater than the mean of the control group ships.", may be made with 99% confidence.

The factor which contributed the most to the difference between the test group and the control group, as shown by the above test, was the average manhours for corrective maintenance. The average manhours for corrective maintenance for the test group ships were significantly higher than the averages for the control group ships.

Another test was made to determine if there were significant differences between the test group ships and the control group ships. This test was done by analysis of variance (ANOVA) and was designed to show the differences in the accomplishment of preventive maintenance when the ships were in-port or at-sea. For this test, a ship was considered to have been at-sea if, four or more days were spent at-sea that week. The PM completion rates, averaged over the at-sea weeks and over the in-port weeks, were used as a measure of effectiveness. Table 15 shows the results of this test, for the cruisers.

Table 15. Analysis of Variance of the PM Completion Rates;
At-sea versus In-port for EMRM Cruisers

|  | Degrees of Freedom | Sum of Squares | F-Statistic |
|---|---|---|---|
| At-sea/In-port | 1 | 41.45 | 1.45 |
| Test/Control | 1 | 303.44 | 10.63 |
| Interaction | 1 | .48 | .02 |
| Error | 4 | 114.17 | |
| Total | 7 | 459.54 | |

The tabulated $F_{1,4}$ value which corresponds to a level of confidence of 0.05 is 7.7086. Since the computed F-statistic for the At-sea/In-port source of variance is less than the value from the F-tables, no significant difference, between being in-port or at-sea, was indicated for the cruisers. Further, since the computed F-statistic for Test versus Control group is greater than its corresponding F-table value, a difference was indicated between the test group cruisers and the control group cruisers.

The same test was run for the guided missile destroyers. The guided missile destroyer test results are shown in Table 16.

Table 16. Analysis of Variance of the PM Completion Rates;
*At-sea versus In-port* for EMRM Guided Missile Destroyers

|  | Degrees of Freedom | Sum of Squares | F-Statistic |
|---|---|---|---|
| At-sea/In-port | 1 | 5.95 | .02 |
| Test/Control | 1 | 3.0 | .01 |
| Interaction | 1 | .91 | .003 |
| Error | 4 | 1252.04 | |
| Total | 7 | 1261.9 | |

The $F_{1,4}$ value, from F-tables is 7.708 for the 0.05 level of confidence. Since all three of the computed F-statistic values are less than the table value, no significant difference was shown

(1) Between the test group guided missile destroyers and those in the control group;

(2) Whether the guided missile destroyers were in-port or at-sea.

The comparison of the results of these analysis of variance tests and the results of the previous hypothesis test, tend to emphasize the need for a better structured, data collection experiment. Some deficiencies which were found in the data, precluded the author from arriving at more statistically sound conclusions. Data showing the turnover of personnel on the ships, by week, would have contributed greatly to the understanding of changes in the maintenance factors which are dependent on manning. Additionally, it would have been beneficial to have had the ships' operating/in-port periods planned to best show the effects of this very important factor.

## FOOTNOTES

[1] Ninety Fourth Congress, <u>Department of Defense Appropriations for 1976, Hearings before a Subcommittee on Appropriations House of Representatives</u>.

[2] Ibid.

[3] Kmenta, Jan, <u>Elements of Econometrics</u>, p. 233, Macmillan, 1971.

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